TRANSACTIONS

of the

American Foundrymen's Association

Proceedings of the

FORTIETH ANNUAL MEETING

Detroit, Mich.

May 5 to 9, 1936

VOLUME XLIV

EDITED BY
R. E. KENNEDY and N. F. HINDLE

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Officers of the

American Foundrymen's Association

INCORPORATED

President
†*James L. Wick, Jr.
Falcon Bronze Co., Youngstown, Ohio

Vice President
†*H. Bornstein
Deere & Co., Moline, Ill.

Executive Secretary-Treasurer
*C. E. Hoyt

Assistant Secretary-Treasurer
Jennie Reininga

Technical Secretary
R. E. Kennedy

Assistant Technical Secretary
N. F. Hindle

Director, Safety and Hygiene Section
E. O. Jones

222 W. Adams St., Chicago, Ill.

MEMBERS OF THE BOARD OF DIRECTORS

(In addition to the President, Vice President and Executive Secretary)

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Chicago, Ill.

†*D. M. AVEY
The Foundry, Penton Bldg.
Cleveland, Ohio

*E. O. BEARDSLEY,
Beardsley & Piper Co.
Chicago, Ill.

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MARSHALL POST
Birdsboro Steel Foundry & Machine Co.
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*W. L. SEELBACH
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Cleveland, Ohio

L. N. SHANNON
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Birmingham, Ala.

F. A. SHERMAN
Dominion Foundries & Steel, Ltd.
Hamilton, Ont., Canada

SAM TOUR
Lucius Pitkin, Inc.
New York, N. Y.

H. S. WASHBURN
Plainville Casting Co.
Plainville, Conn.

* Member of Executive Committee of Board of Directors.
† Member of Finance Committee.

Report of the Executive Secretary-Treasurer

ANNUAL MEETING, BOARD OF DIRECTORS,
CLEVELAND, JULY 23, 1936

Members of the Board of Directors American Foundrymen's Association:

We submit herewith report of the Executive Secretary-Treasurer for the fiscal year ending June 30, 1936.

Changes in convention dates resulted in two conventions during the fiscal year. The first held at the Royal York Hotel, Toronto, August 20-23, 1935, an enjoyable convention, was saddened by the illness during the week of Vice President B. H. Johnson, resulting in his untimely death in a Toronto Hospital the following week.

This convention, held without an exhibit and devoted entirely to technical and general interest sessions, had a registered attendance of 950.

The second convention of the year, this one with an exhibit, was held in Detroit, May 4 to 9, 1936, as the guests of Detroit Civic Bodies represented by their Convention Bureau and members of the Detroit Chapter of A.F.A. Chapter Chairman Vaughan Reid was also General Chairman of Convention Committees. We are deeply indebted, not only to Chairman Reid but to all Chairman and Committee members for their splendid cooperation. Following the custom of recent years, all entertainment offered was financed through a nominal fee paid by those participating.

The Detroit convention and exhibit was generally proclaimed and accepted by members, visitors, the press and trade papers as one of the best ever staged by and for the Foundry Industry. Unquestionably, a large majority of those attending not only profited thereby but returned home with a greater pride in, and greater confidence for the future of the Foundry Industry. If these annual, major activities of the Association do not accomplish all that, they cannot be economically justified, considering, as we must, the effort, time and money expended.

MEMBERSHIP

In our report for the year ending June 30, 1934 on membership, we recorded a new low for recent years with a book membership of 1239—the lowest point since 1919. By December, as a result of 12 resignations and 68 dropped, and only 46 new members to offset these losses, our book membership was only 1205.

The book membership June 30, 1935 was 1360—a gain of 121—the first time we had recorded a gain in membership since 1930.

With the stimulus of two conventions, the chapter movement and improved business conditions, we secured, during the year just closed, 716 new members giving us a book membership of 2014—an increase of 48 per cent.

FINANCES

In our report to you at the annual Board meeting at Toronto last August, we said it was gratifying, after having operated in the red for

three consecutive years, to show income in excess of expenses, even though the amount was only $376.60. It is far more gratifying now, to report excess of income over expenses for the year just closed as $31,503.20.

Our books were closed and audited as of June 30, by Robert T. Pritchard, C.P.A. of Chicago and you will have report on this audit from the Finance Committee. Supplementing the audit, we have prepared a financial statement showing receipts and disbursements in greater detail.

Our balance sheet of June 30, shows total assets including cash, accounts receivable, supplies on hand, investments at cost, as $54,896.10 as against $24,693.18 at the beginning of the year. The above figures do not include Award Fund investments and interest.

There have been no additions to the Award Fund investments during the year which have a par value of $21,000.00 and a market value as of July 15, of $22,834.00.

In addition, we will have in our Award Fund interest savings account $2,611.87 after reimbursing our general checking account in the amount of $665.00 for the cost of two awards made at the Detroit convention, for Apprentice prizes and certificates for Annual Apprentice Contests.

CHAPTERS

Five Chapters were organized during the past year as follows: Detroit, Milwaukee, St. Louis, Northern California and Birmingham. Added to the four Chapters organized the previous year, Chicago, Northeastern Ohio, Philadelphia and the Quad Cities, we now have nine with a membership of 1031—a little more than half of the total membership of the Association. The report of the Technical Secretary will give more detailed information on Chapter activities.

CAST METALS HANDBOOK

The audit will show cash expended during the year for producing the Cast Metals Handbook, including printing, binding, cuts, etc., $5,947.96. This item does not include cost of mailing, any overhead expense nor editorial and committee expense during the two previous years when the Handbook was in preparation. Receipts will show $7,030.69 from advertising and $3,668.90 from sale of books making a total of $10,699.59. The Technical Secretary's report contains further information of interest on the Handbook.

PUBLICATIONS

In 1920 the Association started publishing a Monthly Bulletin—a 6 x 9 self-covered, eight page folder. In 1924 this was changed to a Quarterly Bulletin which was continued until 1929, the number of pages ranging from 32 to 48.

During all these years, the "Transactions" were printed in Bound Volume form and supplied gratis, to all members. At a meeting of the Board September 12, 1929, it was decided that the material contained in the Bound Volume should be divided into sections and, together with the "Bulletin Material," be published as "Transactions and Bulletin" and mailed to all members with a view to securing wider reading of the

Transactions. The publishing of the Bound Volume was to be continued and distributed gratis, to General Firm members and made available to other members at a nominal fee to cover cost of binding and printing.

Monthly publication of combined "Transactions and Bulletin" was continued for about two years when the frequency of issue was changed to bi-monthly, due to economic conditions.

SUGGESTED CHANGE IN PUBLICATION POLICY

The only justification for any change in publication policy would be better service to Members and to the Foundry Industry. Believing that these interests would be better served, we have recommended to the Special Policy and Association Activities Committee a program of more frequent publication. This includes publishing "Transactions" in four issues during the year, omitting inclusion of any Bulletin Section. Continuing the present policy of printing the Bound Volume and then publishing a Monthly of a page size, 8½ x 11 (standard magazine size). We have prepared for the Committee, complete estimates of cost figures—First, for continuing our present publication policy and second, estimated cost of the proposed change in policy.

SAFETY AND HYGIENE SECTION

At a meeting of the Executive Committee held in Cleveland, January 13, 1936, it was voted to create a Safety and Hygiene Section to make more effective the work the Association had carried on for a number of years on Plant Safety, Good Housekeeping and Protection of Workers.

It was also voted to engage as Director of this Section, Mr. E. O. Jones, for many years associated with one of our member companies, the Belle City Malleable Iron Co., Racine, Wisconsin, and who for the three previous years had been Consultant of the Industrial Relations Bureau of the National Founders Association. On January 27, a letter was addressed to all members of record enclosing copy of news release announcing the organization of this new Section. More about this important activity of A.F.A. will be contained in a special report.

A.F.A. INCORPORATED

June 30 marked the close of the twenty-first year of A.F.A. Incorporated, following twenty years of A.F.A. Unincorporated. Seventeen men served as President of the unincorporated body and an equal number as President of the incorporated body. Those serving more than one term were—Francis Schumann, the first President—1897-1898; Major Jos. T. Spear—1911-1912; Major R. A. Bull—1915-1916; S. W. Utley—1927-1928; Dan M. Avey—1935-1936. The last two named while serving two terms, did not serve two full years due to change in convention dates.

Four have served as Secretary of A.F.A. John A. Penton—1896-1899; Dr. Richard Moldenke—1900-1914; A. O. Backert—1914-1918; C. E. Hoyt—1918 to date.

Our charter of incorporation in the State of Illinois was granted July 3, 1916 and now, having attained our majority as an incorporated body, it is perhaps fitting we take stock of our responsibilities and our ability, as at present organized and supported, to serve the Foundry Industry.

It has frequently been suggested during past months that A.F.A. is at the "Cross Roads" and should stop and consider what direction we should take. That was the purpose of authorizing, at the last annual meeting, appointment by the President of a Committee on Association Policies and Activities. You and others have been asked to submit to that Committee, suggestions for their consideration and to come here today to hear and consider what they will have to offer. If we find we are at the fork in the road, then let us make certain that we take the right fork.

Each year it is my privilege and pleasure to express appreciation on behalf of myself and the members of our staff, for the splendid cooperation of officers, directors, committee members and others. This year, as in years previous, it is no mere gesture of ours but an expression of sincere appreciation for the splendid cooperation we receive from all.

Respectfully submitted,

C. E. HOYT, *Executive Secretary-Treasurer.*

Auditor's Report

July 17, 1936

Mr. Dan M. Avey, President,
American Foundrymen's Association, Inc.,
Chicago, Ill.

Dear Sir:

I have examined the books of the American Foundrymen's Association, Inc., for the year ending June 30, 1936 and submit herewith the following statements:

Exhibit A—Balance Sheet, June 30, 1936
Exhibit B—Income and Expenses for the year
Exhibit C—Surplus, June 30, 1936
Schedule I—Award Funds, June 30, 1936
Schedule II—Reserve Funds, June 30, 1936
Schedule III—Cash Receipts and Disbursements.

The securities comprising the Reserve Fund as shown by the Balance Sheet are stated at cost. The market value thereof at date is $71.95 in excess of the cost.

Similarly the securities comprising the Award Funds, (Schedule I), are shown at cost, the market value being $1313.90 in excess of cost.

The excess Income over Expenses for the year was $31,503.20 to which has been added the amount withdrawn from the Reserve Fund during the year, namely $3797.62, making a total of $35,300.82 added to the Surplus of the year.

Subject to these remarks, it is my opinion that the Balance Sheet as at June 30, 1936 (Exhibit A) attached hereto correctly reflects the condition of the Association at that date and as shown by the books.

Respectfully submitted,

ROBERT T. PRITCHARD
Certified Public Accountant

NOTE: A copy of the auditor's Balance Sheet is shown on the following page.

BALANCE SHEET AS AT JUNE 30, 1936

ASSETS

ASSOCIATION ASSETS	
Cash in Bank, Schedule III	$31,736.43
Accounts Receivable, Dues, etc.	1,279.71
Supplies on Hand	2,880.97
Furniture and Fixtures, less Depreciation Reserve	383.03
Total Association Assets	$36,280.14
RESERVE FUND (Schedule II)	
Investments, Market Value $17,937.50	$17,865.55
Cash in Bank on Savings Account	432.35
	$18,297.90
STEEL CASTINGS TEST FUND	
Cash in Bank on Savings Account	$ 318.06
Grand Total	$54,896.10

LIABILITIES

ASSOCIATION LIABILITIES	
Unpaid Bills	$ 88.05
Dues Paid in Advance	2,790.60
Annuity Contract—Unpaid Balance	8,268.00
Total Association Liabilities	$11,146.65
Surplus—Exhibit C	25,133.49
	$36,280.14
RESERVE FUND—SCHEDULE II	
Principal of Fund	$18,297.90
	$18,279.90
STEEL CASTINGS TEST FUND	
Unexpended Appropriation	$ 318.06
Grand Total	$54,896.10

Reports of Board of Directors, Executive Committee and Board of Awards Meetings

Following the annual meetings of the Board of Directors on August 23, 1935 in Toronto which were reported in Bound Volume No. 43, official meetings were held as follows:

January 13, 1936, Cleveland—Meeting of the Executive Committee and Board of Awards.

May 4, 1936, Detroit—Special Meeting of the Board of Directors.

May 6, 1936, Detroit—Special Meeting of the Board of Directors.

July 23, 1936, Cleveland—Final meeting of the 1935-36 Board of Directors and first meeting of the 1936-37 Board of Directors.

Minutes of these meetings are given below.

Minutes of Meeting of Executive Committee

HOTEL CLEVELAND, JANUARY 13, 1936

Members present: President D. M. Avey; Vice-President James L. Wick, Jr.; Directors: Frank J. Lanahan, R. J. Teetor, E. O. Beardsley, W. L. Seelbach; Executive Secretary C. E. Hoyt.

Others present: Past Presidents and members of Advisory Board E. H. Ballard, B. D. Fuller, T. S. Hammond; Past Director S. C. Vessy; Technical Secretary R. E. Kennedy; E. O. Jones, Director of Safety and Hygiene Section.

President Avey presiding announced that at this the first meeting of the Board or Committees thereof since the death of Past Vice-President B. H. Johnson, he would request all present to stand a moment in silent tribute to the memory of Mr. Johnson.

Following reading of a portion of the minutes of the last meeting of the Board of Directors held in Toronto and published in Bound Volume 43, it was voted to approve minutes without further reading.

Secretary Hoyt submitted a report on membership and on finances for the period July 1 to December 31, 1935.

The Secretary then submitted the following report of all letter ballots of the Board of Directors since last meeting of the Board, August 23, 1935.

September 10, 1935

Authorization for payment of bonus to A.F.A. Chapter treasurers for new members received from their respective chapter territories prior to December 31, 1935, as follows: $10.00 for each General Firm member; $5.00 for each Limited Firm member; $5.00 for each Limited Firm member advanced to General Firm membership.

September 28, 1935

Approval of revised manual for organizing and conducting A.F.A. Chapters.

September 29, 1935

Approval by letter ballot of petition for the organization of a Northern California Chapter of A.F.A.

October 4, 1935

Election by letter ballot of James L. Wick, Jr. as vice-president to serve the unexpired term of B. H. Johnson, deceased.

Election of E. H. Ballard to serve out the unexpired term of James L. Wick, Jr. as director.

Election of Frank J. Lanahan as member of Executive Committee of the Board of Directors.

October 8, 1935

Approval of petition for organizing a Detroit Chapter of A.F.A.

October 10, 1935

Approval of petition for organizing a St. Louis Chapter of A.F.A.

October 15, 1935

Election by letter ballot of Plumb Taylor Bancroft to Life Membership, effective November 1, 1935.

October 20, 1935

Approval of petition for organizing Milwaukee Chapter of A.F.A.

November 12, 1935

Nomination of Vincent Delport, European representative of A.F.A., as the Association's nominee for vice-president of the International Committee of Foundry Technical Associations.

November 20, 1935

Approval of outline in President Avey's letter to the Board of Directors under date of November 25, 1935, for purchasing an annuity for Executive Secretary C. E. Hoyt.

The Secretary reported that the records would show that no negative votes were cast on any of the above letter ballots, and that with the exception of the election of officers, directors and committee members where Messrs. Wick, Ballard and Lanahan had failed to vote for their own election, the full letter ballot of the Board had been cast.

President Avey announced that a committee had been appointed to draft resolutions on the death of Vice-President B. H. Johnson, and called on Secretary Kennedy to submit a report for the committee.

On motion duly seconded, the committee was instructed to prepare the resolutions in the form in which they had been presented, these to be spread upon the records of the Association, printed in the bound volume of Transactions, and an engrossed copy presented to the deceased's family.

Secretary Kennedy asked approval for showing in the current number

of bound volume, a likeness of past vice-president, Mr. Johnson, where it was customary to show the likeness of the president; and that the likeness of President Avey, who had succeeded himself as president, appear in the next issue of Transactions. On motion duly seconded, this recommendation was approved.

President Avey then called on S. C. Vessy, Foundry Equipment Manufacturing Association representative on American Standards Association, Project Z-9, Safety Code for Exhaust Systems, to submit a report of a meeting held in New York, January 6.

Secretary Hoyt supplemented the report of Mr. Vessy by reporting conversations he had with J. R. Allan, A.F.A. representative on this committee.

Both Mr. Vessy and Mr. Allan urged the importance of the work the A.F.A. was doing in developing codes for industry, and urged that this work be watched carefully and contributed to generously by members who are able to contribute from their experience and knowledge of subjects under consideration.

Convention and Exhibit Plans

Secretary Kennedy reporting on plans for convention program, stated that in response to request, arrangements were being made for holding a majority of sessions in the morning and some evening sessions, leaving afternoons as free as possible for inspection of exhibits.

Secretary Hoyt reporting on the hotel situation, asked that the committee designate the hotel in Detroit that would be known as headquarters hotel. It was moved by Mr. Seelbach, seconded by Mr. Beardsley, that the Hotel Statler be designated as headquarters, with the Book-Cadillac Hotel as alternate headquarters.

Secretary Hoyt reported on exhibit plans, submitting a lay-out of space and a schedule of prices ranging from $1.00 to $1.25 a square foot, with maximum rate applying to spaces of minimum depth, and the minimum rate applying to spaces of maximum depth. On motion duly seconded, the plans and schedule of prices were approved.

Rules and regulations for conduct of exhibits and the following schedule of hours, was then approved. Formal opening, 9:00 A.M. Tuesday, May 5; final closing, 4:00 P.M. Saturday, May 9. Open hours of show during the week—9:00 A.M. to 6:00 P.M.

Report of Nominating Committee

E. H. Ballard, Chairman 1936 Nominating Committee, reported that at the meeting of the committee held preceding the Executive Committee meeting, the following officers and directors were nominated:

For President:

James L. Wick, Jr., Falcon Bronze Co., Youngstown, Ohio.

For Vice-President:

H. Bornstein, Deere & Co., Moline, Ill.

For Directors, to serve terms of three years each:

D. M. Avey, Penton Publishing Co., Cleveland, Ohio.
J. R. Allan, International Harvester Co., Chicago, Ill.
Carl C. Gibbs, National Malleable & Steel Castings Co., Cleveland, Ohio.
Marshall Post, Birdsboro Steel Foundry & Machine Co., Birdsboro, Pa.
L. N. Shannon, Stockham Pipe Fittings Co., Birmingham, Ala.

Frank J. Lanahan, Chairman of the Board of Awards, reported that at a meeting of the Board held previous to this meeting, it was voted to confer a J. S. Seaman Gold Medal and a J. H. Whiting Gold Medal of A.F.A. at the annual convention in May, and that following the established custom, announcement of medallists would be withheld until shortly before convention date.

Secretary Kennedy reported plans were well under way for organizing the Birmingham Chapter under the leadership of L. N. Shannon.

Organization of Safety and Hygiene Section

President Avey announced that the next order of business would be consideration of a plan for organizing a safety and hygiene section of A.F.A. In reviewing considerations that had been given to such a step, Secretary Hoyt read from the minutes of the Executive Committee meeting held March 5, 1935 and reported a conference held during the Toronto convention.

The Secretary then read from the minutes of the last annual meeting of the Board, at which time it was unanimously voted to refer the question of organizing a safety and hygiene section to the officers and to the executive committee with power to act.

President Avey reported that following adjournment of that meeting there had been exchanges of correspondence, and that at the November meeting of the N.F.A. in New York a conference of Executive Committee members was held with D. E. Cummings, field representative of Saranac Laboratory, at which time Mr. Cummings was requested to submit a program for conducting research on safety and hygiene and rendering service to A.F.A. members.

President Avey then called on Secretary Hoyt to report further developments, including negotiations with officers of the Milwaukee Chapter, with Mr. Cummings and E. O. Jones, Consultant, Industrial Relations Bureau, N.F.A.

Mr. Hoyt reported further on a conference he had with Mr. Taylor, Secretary, and Mr. McClintock, Commissioner of the N.F.A., concerning the availability of Mr. Jones to serve as director of a safety and hygiene section of A.F.A.

Following discussion, it was moved by Mr. Lanahan that there be organized a Safety and Hygiene Section in accordance with recommendations of President Avey, Vice-President Wick and Secretary Hoyt. Motion duly seconded and unanimously carried.

Moved by Mr. Seelbach, seconded by Mr. Wick, that E. O. Jones be engaged as Director of the newly created Safety and Hygiene Section, and that the period of his engagement be to the end of the fiscal year,

June 30, at a salary of Five Hundred ($500.00) Dollars per month, services to begin as soon as could be arranged.

Moved by Mr. Ballard, seconded by Mr. Beardsley, that the Executive Secretary address a communication to the N.F.A., expressing appreciation of their cooperation in making available the services of Mr. Jones.

Moved by Mr. Seelbach, seconded by Mr. Wick, that the officers of the Association be authorized to renew lease for office space in the Adams-Franklin Building, with the usual cancellation provision; also, secure the necessary additional space as provided and that the Executive Secretary be authorized to purchase necessary office equipment to take care of enlarged activities. Motion was carried.

Moved, seconded and carried, that the Executive Secretary be authorized to purchase an additional supply of membership emblems.

Secretary Hoyt recommended to the Board to authorize pro-rating dues of new members on a quarterly basis, providing that members elected during the months of July, August and September be credited with membership to the following June 30; that members elected during October, November and December be credited with membership to October 1 of the following year; that members elected during January, February and March be credited with membership to December 31; and members elected during the months of April and May be credited with membership to April 1.

Moved, seconded and carried, that the above recommendations be approved, and that as a special inducement to securing members following Spring convention each year and during the month of June, such members be credited with membership to June 30 of the following year.

Secretary Kennedy discussed plans for revisions to the Cast Metals Handbook, and submitted a report on the work of the Committee on Alloys of Cast Iron.

On motion duly seconded, meeting of the Executive Committee stood adjourned.

Respectfully submitted,

C. E. HOYT, *Executive Secretary*

Minutes of Board of Awards Meeting

HOTEL CLEVELAND, CLEVELAND, JANUARY 13, 1936

This meeting followed a meeting of the 1936 Nominating Committee and preceded the meeting of the Executive Committee of the Board of Directors.

Members present: Frank J. Lanahan, chairman, Past Presidents F. Erb, E. H. Ballard, and T. S. Hammond. *Absent:* Past Presidents A. B. Root, Jr., S. W. Utley, and N. K. B. Patch. C. E. Hoyt acted as secretary.

Mr. Hoyt reported correspondence between members of the Board of Awards and presented a financial statement showing cash on hand in each of the award interest funds. He then proposed consideration of giving both a J. S. Seaman and a J. H. Whiting Medal in 1936.

Medal Awards

Following discussion, it was moved by Mr. Ballard, seconded by Mr. Hammond, and unanimously voted to recommend to the Board of Directors that a Joseph S. Seaman Medal and Award of the American Foundrymen's Association be conferred on Dr. H. Ries of Cornell University in recognition of his work on foundry sands, presentation to be made at the annual banquet during the 1936 convention.

It was then moved by Mr. Hammond, seconded by Mr. Erb, and unanimously voted to recommend to the Board of Directors that a J. H. Whiting Medal and Award of the A.F.A. be conferred on David McLain of Milwaukee in recognition of his pioneer work in the use of steel scrap in cupola charges and for his work in promoting better furnace practice.

Mr. Hoyt reported that $1,000 in United States government bonds in the J. S. Seaman award fund had been called. On motion duly seconded, the treasurer was instructed to place the proceeds of the sale of these bonds in a saving account with the Brighton Five Cents Savings Bank, Brighton, Mass.

Apprentice Awards

Mr. Hoyt reported that the A.F.A. Committee on Apprentice Training desired to re-establish, at the Detroit Convention, apprentice contests in molding and pattern making, provided the Board of Awards made available the usual funds for cash prizes.

On motion duly seconded it was voted to make funds available for cash prizes of $40.00, $25.00, and $15.00 each for steel molding, gray-iron molding, and pattern making contests and for providing apprentice winner certificates.

The question of the Obermayer prize was discussed but no action was taken pending some definite program for use of funds now available in the Obermayer award interest account.

On motion duly seconded, the meeting stood adjourned.

Respectfully submitted,

C. E. HOYT, *Secretary*

Minutes of Special Meeting of Board of Directors

STATLER HOTEL, DETROIT, MAY 4, 1936

This meeting, which preceded the annual alumni dinner and meeting, was called to order by President D. M. Avey with the following directors present: Vice President J. L. Wick, Jr., E. H. Ballard, E. O. Beardsley, R. F. Harrington, W. J. Cluff, W. L. Seelbach, Sam Tour, L. S. Peregoy, H. S. Washburn, and Executive Secretary C. E. Hoyt.

Secretary Hoyt stated that it was a customary procedure to elect the retiring president to Honorary Life Membership and that it was also an established practice to elect the medallists of each year to Honorary Life Membership. He stated further that the By-Laws provided that all

Honorary Life Members should be elected by members of the Association at a regular meeting thereof, voting on a recommendation of the Directors that such memberships be conferred. Therefore, a motion would be in order for recommendations for such memberships at the annual meeting May 7.

Honorary Life Membership

It was moved by Mr. Ballard and seconded by Mr. Seelbach that the Board of Directors recommend to the members of the Association that retiring President Dan M. Avey be elected to Honorary Life membership. The motion was put by Vice President Wick and unanimously carried.

Secretary Hoyt stated that the two medallists of the year were Dr. H. Ries and David McLain and that Dr. Ries was already an Honorary Life Member, having been elected in 1924. It was moved by Mr. Harrington and seconded by Mr. Ballard that the Board of Directors recommend to the members that David McLain, J. H. Whiting Medallist, be elected to Honorary Life Membership. The motion was put by President Avey and unanimously carried.

Mr. Hoyt explained the difficulty that might be encountered at the exhibit halls by excessive noise from operating exhibits and requested the appointment of a committee to work with him in securing the cooperation of exhibitors who had noisy operating exhibits. On motion duly seconded, the president was authorized to appoint a committee of five to cooperate with the manager of exhibits.

The president named Messrs. Ballard, Tour, Washburn, Seelbach, and Peregoy as members of such a committee.

On motion the meeting adjourned to convene again during the week at the call of the president, if in his judgment there should be occasion for a meeting. Following adjournment, the directors joined past presidents and directors, 44 in all, who had assembled for the annual alumni dinner and meeting.

Respectfully submitted,

C. E. HOYT, *Executive Secretary*

Minutes of Special Meeting of Board of Directors

STATLER HOTEL, DETROIT, MAY 6, 1936

Members present: Pres. D. M. Avey, Vice Pres. J. L. Wick, Jr., W. L. Seelbach, F. A. Sherman, F. J. Lanahan, E. H. Ballard, R. F. Harrington, H. S. Washburn, E. O. Beardsley, and W. J. Cluff.

Others present: E. O. Jones, Director of Safety and Hygiene Section, and C. E. Hoyt, Executive Secretary.

This special meeting of the Board was called for the purpose of receiving a report from Mr. Jones on a meeting called in Washington by (Secretary of Labor) Frances Perkins.

Mr. Hoyt stated that on receipt of the invitation from Secretary

Perkins to send a representative to a conference in Washington, he corresponded with Pres. Avey and Vice Pres. Wick, and it was agreed that Mr. Jones would be instructed to attend the conference to ascertain just what was being considered, in other words as an observer, and to report back.

Pres. Avey then called on Mr. Jones for a report of the conference. Mr. Jones speaking said that there was some 40 representatives of industry present. Following lengthy discussions a vote was taken to determine whether a national symposium should be held in Washington to discuss the silicosis problem. The result of this vote was 37 for such a conference or symposium and 3 opposed. Mr. Jones, as the representative of the Foundry Industry, after conferring with Roger Williams, Vice Pres., Richardson and Boynton Co., who was present as the alternate representative of the Foundry Industry, voted against the calling of such a conference as was proposed.

Mr. Jones reported further that later this program was modified by the National Advisory Committee who suggested that committees be appointed for the purpose of making a thorough study of conditions, reporting back their findings at a later date.

As a result of the recommendations of the National Advisory Board, it was decided to appoint the following committees: Medical, Economic, Regulatory and Engineering. Acting upon the recommendations of the committee, Secretary Perkins invited Mr. J. R. Allan, International Harvester Co., Chicago, and E. O. Jones of the A.F.A. to serve on the Engineering Committee.

Mr. Hoyt stated that Mr. Allan was accepting appointment on this committee and would like to ask the Board of Directors for instructions re acceptance of appointment by Mr. Jones.

Pres. Avey canvassed the members present and following discussions the motion prevailed authorizing the acceptance by Mr. Jones of service on the Engineering Committee.

Mr. Hoyt read a memorandum from Technical Secretary Kennedy, conveying a request from Dr. H. Ries, Director of Foundry Sand Research, that the Board of Directors approve "Tentative Purchase Forms" for purchase of foundry sands, subject to approval of forms by the Executive Committee of the Committee on Foundry Sand Research. Moved by Mr. Harrington, seconded by Mr. Ballard that vote of approval be given. Motion carried.

Discussions then followed on what action, if any, the Board of Directors, the Association or any Committees could take in connection with National Government Policies. No action was taken but it was the unanimous opinion of those present that individuals should be encouraged to take active interest, working through such groups of organized bodies as could properly function in these matters.

There being no further business the meeting stood adjourned subject to call by the president, if it was found advisable to convene again during Convention Week.

Respectfully submitted,

C. E. HOYT, *Executive Secretary*

Minutes of Annual Meeting of Board of Directors

STATLER HOTEL, CLEVELAND, JULY 23, 1936

This, the final meeting of the 1935-1936 Board of Directors, was called to order with President Dan M. Avey presiding.

Present: President D. M. Avey; Vice President James L. Wick, Jr.; Directors E. H. Ballard, T. S. Hammond, R. F. Harrington, R. J. Teetor, E. O. Beardsley, L. S. Peregoy, E. W. Campion, W. L. Seelbach, Frank J. Lanahan, Sam Tour, W. J. Cluff, H. S. Washburn; H. Bornstein, Vice President Elect; Directors Elect James R. Allan, L. N. Shannon, Marshall Post; Executive Secretary, C. E. Hoyt, Technical Secretary, R. E. Kennedy, Director of Safety and Hygiene, E. O. Jones.

For the first time in many years there were no Past Presidents or members of the Advisory Board present.

Minutes of the Executive Committee meeting at Cleveland, January 13, 1936 and of two special meetings of the Board, held May 4 and May 6, during the annual convention, were read and approved.

Report of the Executive Secretary-Treasurer was read and on motion of Director Tour, accepted and ordered filed with special appreciation to the Secretary.

Report of Technical Secretary was presented without reading with copies for all present and on motion, the report and recommendations contained therein were referred to the incoming Board.

The report of the Manager of Exhibits was read and on motion, accepted and ordered filed.

Report of Finance Committee

Report of the Finance Committee was presented by Chairman Frank J. Lanahan who reviewed the report of the Auditor for the year closing June 30, and commented on the improved financial condition showing a cash balance of $31,736.43 as against $909.51 for the previous year. On motion duly seconded, the report of the Finance Committee and the Auditor's report, were accepted and ordered filed.

President Avey, reporting further for the Finance Committee, stated that the balance of premiums due on the annuity policy for Secretary Hoyt which the Association had contracted for with the Equitable Life Assurance Society as of date of August 1, would be $7833.37 and that it was the recommendation of the Finance Committee that the premiums be paid in full as of that date, applying the proceeds of $3150.00 from the sale of the California Water Service Bonds in the Sinking Fund; the balance from the General Fund, effecting a saving in interest of approximately $434.00.

It was moved by Mr. Lanahan that the Officers of the Association be instructed to pay premiums in full as of date of August 1, and when received, deposit the proceeds from the sale of the California Water Service Bonds to the credit of the general checking account. Motion was seconded by Vice President Wick and unanimously carried.

Secretary Hoyt called attention to his report on publication and sales of Cast Metals Hand Book and recommended that an honorarium of $300.00 be paid R. A. Bull as appreciation of services rendered in the preparation of the book. It was moved by Mr. Lanahan that such an honorarium be paid Mr. Bull. The motion was seconded by Messrs. Bornstein, Harrington and Tour and was unanimously carried.

Policies and Activities Committee Report

The Chair next called for the report of the special committee on Association policies and activities with Frank J. Lanahan, Chairman, representing Malleable, and Directors Wick, Peregoy, and Seelbach representing Non-Ferrous, Steel and Gray Iron respectively and Past Director H. S. Simpson representing Equipment and Supplies.

Chairman Lanahan stated that, prompted by invitations extended to all officers, directors, past officers and directors and others, the committee had received many helpful and valuable suggestions recommending greater emphasis be put on certain activities of Association and suggesting for the consideration of the committee, other activities that might be undertaken on behalf of the Foundry Industry.

Mr. Lanahan, continuing, stated that the committee had held a meeting on the morning of the previous day and a joint meeting with the Executive Committee in the afternoon and had certain recommendations to make. He then called on Mr. Peregoy.

Mr. Peregoy reported that it was the unanimous recommendation of the Policy Committee and of the Executive Committee that the work of the Safety and Hygiene Section established by the Executive Committee at a meeting held January 13, be continued and that E. O. Jones be retained as Director.

Mr. Lanahan then reported that it was the unanimous recommendation of the Policy Committee and of the Executive Committee that the by-laws be amended to provide for the office of Executive Vice President. Continuing, Mr. Lanahan said there was a great deal of work to be done in reviewing suggestions offered and in considering Association policies, recommending that the committee be continued or a new committee appointed to carry on. On motion duly seconded, it was voted to accept the report of the committee and refer their recommendations to the incoming Board.

Technical Secretary Kennedy presented an outline of technical activities of the Association and on motion duly seconded, his recommendations were referred to the incoming Board.

Secretary Hoyt requested the privilege of submitting copies of report he prepared on the Safety and Hygiene Section, to the Directors by mail. This was approved.

Report Joint Committee on Compensation Insurance Rates

The Chair called on Directors Ballard and Peregoy to report the work done during the past year by the joint committee of A.F.A. and N.F.A.

appointed to meet with a special committee of the National Rating Board on compensation insurance rates. Mr. Ballard speaking, stated the committee consisted of Roger Williams, vice president, Richardson & Boynton Company, Chairman; Messrs. A. B. Root, Jr., L. S. Peregoy and himself with Messrs. Don Cummings of the Saranac Laboratories and E. O. Jones, members ex officio and advisers.

The first meeting of the committee was held in New York, November 7; a second meeting November 22; the third held on January 23 and 24, and the last meeting July 7. Mr. Ballard made the statement, supported by Messrs. Peregoy, Washburn and others, that the Industry never would know and never could know, the money the Industry had been saved as a result of these joint conferences and negotiations. On motion duly seconded, a vote of thanks was tendered this committee in appreciation of the good work it was doing.

The Chair called on Vice President Wick to report on Chapter Officers' conference held during the Detroit convention, over which he presided. The report was received and referred to the incoming Board.

Mr. Wick moved that a vote of gratitude and appreciation be given to the officers and members of the Detroit Chapter for their splendid assistance in handling the Detroit convention. This was seconded and carried.

Report of Election of Officers

The Executive Secretary reported that, at the annual business meeting of the Association, Detroit, May 6, James L. Wick, Jr., had been duly declared elected President and H. Bornstein, Vice President, to serve terms of one year each and James R. Allan, Dan M. Avey, Carl C. Gibbs, Marshall Post and L. N. Shannon declared elected Directors to serve terms of three years each, the above Officers and Directors to take office following adjournment of this Board meeting.

Retiring President Avey introduced President Wick, Vice President Bornstein and Directors Allan, Shannon and Post (Mr. Gibbs was not present), commented on the pleasure that it had been to serve the Association as President and turned the meeting over to President Wick.

Mr. Wick announced that before adjourning for luncheon he would appoint as members of the Nominating Committee to nominate officers, as provided for in the by-laws, Messrs. Lanahan, Allan and Washburn. The meeting then adjourned for luncheon in the adjoining room.

For luncheon the Board had as guests, Col. Rose, Executive Vice President, Gray Iron Founders' Society, S. C. Vessy, Past Director A.F.A. and Mark Egan, Manager, Cleveland Convention Bureau.

Following luncheon and before resuming in Board meeting, President Wick addressed those present and in well chosen words expressed his appreciation of the honor bestowed upon him; pledged to discharge his duties to the best of his ability and asked the cooperation of officers, directors and all members. He then called on Director Frank Lanahan to express for all, the appreciation of services rendered by those who were retiring from the Board.

With well chosen words and pleasing manner, Mr. Lanahan in turn,

addressed Retiring Directors Ballard, Hammond, Harrington, (Mr. Teetor had left), and then Mr. Avey.

The Chair then introduced the guests, Col. Rose and Mr. Egan who responded, following which he announced that the Board meeting would reconvene in the adjoining room and invited all those whose terms of office had expired to remain for the new Board meeting.

Respectfully submitted.

C. E. HOYT, *Executive Secretary.*

Minutes of the First Meeting of the 1936-1937 Board of Directors

STATLER HOTEL, CLEVELAND, JULY 23, 1936

Members Present: President James L. Wick, Jr., Vice-President H. Bornstein; Directors E. O. Beardsley, E. W. Campion, W. L. Seelbach, Frank J. Lanahan, Sam Tour, W. J. Cluff, L. S. Peregoy, H. S. Washburn, James R. Allan, D. M. Avey, Marshall Post, L. N. Shannon.

Directors Absent: C. E. Davis, Carl C. Gibbs, F. A. Sherman.

Others Present: Retiring Directors E. H. Ballard, R. J. Teetor, R. F. Harrington; Executive Secretary, C. E. Hoyt, Technical Secretary, R. E. Kennedy, Director of Safety and Hygiene, E. O. Jones.

Organization of New Board

President Wick presiding announced the Board would proceed to organize in accordance with the provisions of the By-Laws and called for the report of the committee appointed to nominate officers to be elected and four (4) directors to serve as members of the Executive Committee.

Frank J. Lanahan, as Chairman, reporting for Directors Allan and Washburn, the other members of the committee, said that they would first recommend that the offices of Executive Secretary and Treasurer be combined in accordance with the provisions of the By-Laws, and he would so move. Motion seconded and carried.

Mr. Lanahan, continuing, said the committee had nominated for officers the following:

Executive Secretary-Treasurer—C. E. Hoyt
Technical Secretary—R. E. Kennedy
Manager of Exhibits—C. E. Hoyt
Assistant Secretary-Treasurer—Jennie Reininga
Assistant Technical Secretary—N. F. Hindle

The Chair called for further nominations. There being none, he declared the nominations closed. On motion, duly seconded, the officers as nominated were declared elected to serve until the end of the fiscal year, June 30, 1937, or until their successors were elected and qualified.

Mr. Lanahan then placed in nomination for members of the Executive Committee, Directors L. S. Peregoy, W. L. Seelbach, E. O. Beardsley, Dan

M. Avey, and moved their election. Motion was seconded and unanimously carried.

Mr. Lanahan, continuing, said that acting upon the recommendation of the Retiring Board the committee would nominate for Director of Safety and Hygiene, Mr. E. O. Jones, and moved his election. Motion seconded and carried unanimously whereupon Mr. Jones was declared elected as Director of Safety and Hygiene for the ensuing year.

Report of Finance Committee

President Wick next called for the recommendations of the Finance Committee on the salaries of officers, and announced that, following custom, those officers present who had been elected by the Board would retire while salaries and compensation were being discussed.

Report of the Finance Committee was then received, and by unanimous vote salaries of officers for the year beginning July 1, 1936 were authorized as follows:

C. E. Hoyt, as Executive Secretary-Treasurer.....$350.00 per month
R. E. Kennedy, as Technical Secretary.....$475.00 per month
C. E. Hoyt, as Manager of Exhibits.....$350.00 per month
Miss Jennie Reininga, as Asst. Secretary-Treasurer.$250.00 per month
Retroactive to January 1, 1936
N. F. Hindle, as Asst. Technical Secretary.....$225.00 per month
Retroactive to January 1, 1936
E. O. Jones, as Director of Safety and Hygiene....$500.00 per month

Disbursement of Funds Resolutions

On motion, duly seconded, the following resolutions on disbursement of funds were unanimously adopted:

"Resolved that resolutions required by the Harris Trust and Savings Bank of Chicago authorizing withdrawal of funds, are hereby approved and the Executive Secretary authorized to certify thereto.

"Resolved that checks for withdrawal of funds deposited in the name of the Association and withdrawal of all securities in the sinking fund in the Department of Exhibits of the American Foundrymen's Association held by the Trust Department of the Harris Trust and Savings Bank, and the withdrawal of all interest savings accounts of the Association, shall require two signatures as follows:

J. L. Wick, Jr., President, and C. E. Hoyt, Executive Secretary; or H. Bornstein, Vice President, and C. E. Hoyt, Executive Secretary;

or J. L. Wick, Jr., President, and H. Bornstein, Vice President.

"Be It Further Resolved that the Board of Directors authorize an Executive Secretary Expense Account of one thousand dollars ($1,000.00) said account to be reconciled at the end of each month by full statement of expenditures; withdrawal checks to be signed by the Executive Secretary or the Assistant Secretary.

"Resolved that the officers of the Association are hereby authorized to open a special checking account in the name of the American Foundrymen's Association in the convention city, they to determine how this account shall be opened and the signatures required for the withdrawal of funds.

"Resolved that the Executive Secretary-Treasurer be authorized

to reimburse traveling expenses for members in attendance at any regularly called Board of Directors' or committee meeting with the following exceptions:

"No expenses shall be paid to Directors or committee members for attendance at meetings held during the week of the annual convention of the Association unless specifically authorized by the Executive Committee.

"When meetings are held in conjunction with other committees or associations the Executive Secretary or the Executive Committee are authorized to determine what portion of the expense of attendance at such meetings shall be paid by the Association."

On motion duly seconded, the bonds of C. E. Hoyt, Executive Secretary-Treasurer and Jennie Reininga, Assistant Secretary-Treasurer, were placed at $5,000.00 each, premiums to be paid by the Association.

On motion duly seconded, the President was authorized to make or approve all appointments for standing or special committees not provided for in the by-laws or by special act of the Board.

Foundry Sand Research

Technical Secretary Kennedy submitted a request on behalf of the Sand Research Committee for an appropriation to conduct special research on the effect of elevated temperatures on foundry sands as follows:

Construction of apparatus for making high temperature test	$ 400.00
Payment of research assistant to carry on test	1,500.00
Expenses for miscellaneous research work to be carried on by the Sand Research Committee	500.00
Expense of Technical Director including clerical assistants and attendance on committee meetings	300.00
	$2,700.00

Secretary Kennedy stated the committee had received some promises of financial assistance and Secretary Hoyt referred to procedure approved by previous Boards for raising special funds.

On motion duly seconded, the Board voted to approve the request of the Committee on Sand Research and of some effort being made to support this work through contributions from Industry.

Steel Casting Design

Secretary Kennedy presented a request of the Steel Division for an appropriation of $500.00 to pay for the preparation of a treatise on the design of steel castings.

Directors Peregoy and Campion, representing Steel, commented on the importance of this work.

Secretary Hoyt called attention to a recent report from R. A. Bull, A.F.A. representative on the joint committee for Investigation of Phosphorus and Sulphur in Steel advising that this work had been discontinued and the committee discharged.

Mr. Hoyt stated further that there was, according to the last audit, a cash balance of $318.06 in a special fund for this purpose and that it

was Major Bull's suggestion that this sum be made available for the proposed work in design of steel castings.

Following discussion it was moved by Mr. Campion, seconded by Mr. Post that the balance of $318.06 in the special steel casting test fund and sufficient additional funds up to a total of $500.00 be appropriated for carrying on this work. Motion carried.

Policies and Activities Committee Report

President Wick, referring to the report of the special committee on Association policies and activities presented at the morning meeting, called on Chairman Lanahan to present the recommendations that had been made by the previous Board.

Mr. Lanahan stated that the special committee on Association activities and the Executive Committee had jointly recommended that pending the approval of an enlarged program of activities, the Board of Directors approve submitting to the membership amendments to the by-laws providing for the election of an Executive Vice President.

Following discussion it was moved by Mr. Tour that the policy committee with the Executive Secretary, draft the necessary changes in the by-laws to provide for the election of an Executive Vice President, a Secretary, a Treasurer, a Technical Secretary and a Manager of Exhibits in accordance with the recommendations of the previous Board and that the Executive Secretary be directed to submit these proposed changes in the by-laws to the membership for letter ballot and that when and if the recommended changes are approved any vacancies so created be filled by the Board of Directors. Motion seconded by Mr. Washburn and carried.

Proposed Changes in By-Laws

(The following draft of amendments prepared following adjournment in accordance with the above action and submitted to the Directors for approval by mail is inserted in the minutes of this meeting to complete the records.)

1. Leave out word "Executive" wherever it appears before "Secretary" in Article II, Section 2—Article IV, Section 1—Article VIII, Section 4 and Section 5—Article IX, Section 3—Article XX, Section 1.

2. Article IV, *Section 1.*
   Change to read as follows:
   The officers shall consist of a President and a Vice President elected annually from and by the members; an Executive Vice President; a Secretary; a Treasurer; a Technical Secretary; a Manager of Exhibits and such other officers and assistants as shall be determined from time to time by resolution of the Board of Directors; these officers and assistants to be elected when practicable, at the annual meeting of the Board of Directors. Any offices except those of President and Vice President, in the discretion of the Board of Directors, may be combined.

3. Article VI—Duties of officers.
   No change in Sections 1 and 2.

Section 3—

The Executive Vice President shall be, under the direction of the President and of the Board of Directors, the administrative officer of the Association.

4. *Section 4*—

The Secretary shall be the custodian of the records of the Association. He shall prepare the business therefor and duly record proceedings of the meetings of the Association, the Board of Directors and of the Executive Committee. He shall perform the duties of the Executive Vice President when the latter is absent and perform such other duties as shall be prescribed from time to time by resolution of the Board of Directors.

5. *Section 5*—

The Treasurer shall collect all dues, assessments or moneys due to the Association and deposit same in the name of the Association in such bank or banks as shall be approved by the Board of Directors. He shall pay all bills when certified to, in a manner prescribed by the Board of Directors. He shall present annually to the Board of Directors a balance sheet of his books as of the thirtieth of June and shall perform such other duties as prescribed, from time to time, by the Board of Directors. He shall give a bond, the amount of which shall be fixed by the Board of Directors, the premium on said bond to be paid by the Association.

6. Article X, *Section 1*—

At the annual meeting of the Board of Directors, the Board shall elect four of their members who, together with the President, Vice President and Executive Vice President shall constitute an Executive Committee with power to act for the Directors in the interim between meetings of the Board in all matters which may thus be decided with propriety.

Publication Policy Recommendations

President Wick next called on Secretary Hoyt to present recommended changes in publication policies incorporated in the Executive Secretary's annual report.

After reviewing publication policies over the period of years since the Association was incorporated which at present included a bi-monthly publication containing *Bulletin* and *Transactions* sections, an annual bound volume of Transactions and special publications such as Castings Symposia, Cast Metals Hand Book, etc., Mr. Hoyt said:

"The only justification for any change in publication policy would be better service to members and the Foundry Industry. Believing that the interests of the members and the Foundry Industry can better be served through a change in policy we recommend to this special policy and activities committee for their consideration a program of more frequent publications that would include publishing *Transactions* in four issues during the year without the *Bulletin* section, continuing

the present policy of printing the bound volume and adding a new monthly publication of a page size—8½x11."

Continuing, Secretary Hoyt said that they had prepared for the committee complete estimates of cost figures for continuing present publication policies to the increased membership and estimates of cost for the proposed change in policy which represented a very slight increase of cost per member.

Director Tour wanted to know if there was a Publication Committee to consider these recommendations. If not he would recommend that such a committee be created.

Following discussion it was moved by Mr. Cluff, seconded by Mr. Washburn that the matter of change in publication policies be referred to the Executive Committee.

Alloys of Iron

Secretary Kennedy read his statement reviewing the developments of the Alloys of Iron Committee of Engineering Foundation to the support of which the Board of Directors in 1929 acting upon the recommendation of our Research and Appropriation Committee, authorized annual appropriations of $1,000.00 for five years and to which the Association had contributed the sum of $2,000.00.

Mr. Kennedy's report brought out the fact that the results of the work of the committee had not been of the value to the Foundry Industry the Board, in authorizing appropriations, had been given to understand it would be.

Following discussion participated in by members of the Board who are somewhat familiar with this work the following resolution was moved and unanimously adopted:

"RESOLVED that it is the feeling of the Board of Directors of the American Foundrymen's Association that the Foundry Industry is not receiving such returns from the work of the Alloys of Iron Committee as to justify the Association at this time contributing further to the financial support of this work. Furthermore, the Board believes that the contribution of two thousand dollars ($2,000.00) already made by the A.F.A. is a generous contribution considering the benefit the Foundry Industry has received from the work of this Committee. Therefore the Secretary is hereby directed to inform the Engineering Foundation of this expression of the Board of Directors of the American Foundrymen's Association."

Plan of 1937-38 Conventions

President Wick announced the next order of business would be consideration of invitations for the holding of the 1937 and the 1938 conventions of the Association and called on Secretary Hoyt for a report.

Mr. Hoyt stated that many invitations had been received for 1937 and some for 1938; that those best supported for 1937 were from cities of Milwaukee and St. Louis where the Convention Bureaus had enlisted the active support of A.F.A. Chapters in those cities; from Cincinnati, Columbus and Baltimore whose official invitations had been well supported by foundrymen and A.F.A. members in the respective cities; from New York where the securing of such support had been pledged.

Continuing, Mr. Hoyt stated that the cities of Cleveland and Chicago had extended invitations for 1938 supported by the Boards of Directors of A.F.A. Chapters in those cities. Also by proposals setting forth terms for use of auditorium exhibit facilities. He then referred to the report of the Manager of Exhibits presented at the morning session in which he reviewed the history of exhibits from the time the Association was incorporated in 1916.

Following further discussion, it was moved that all invitations be referred to the Executive Committee for further consideration, they to report back to the Board recommendations as to time, place and character of the 1937 convention for letter ballot.

It was moved, seconded and carried that the Board express to the Cleveland Hotel Men's Association, appreciation for its hospitality during the two-day sessions.

On motion duly seconded, the following resolution was adopted:

> "Resolved that the Executive Committee of the Board be empowered to act for the Board in the interim between Board meetings on all matters requiring Board action."

Whereupon Chairman Wick declared the first meeting of the 1936-1937 Board of Directors of the American Foundrymen's Association adjourned.

Respectfully submitted,

C. E. HOYT, *Executive Secretary.*

Report of Manager of Exhibits

ANNUAL MEETING, BOARD OF DIRECTORS,
CLEVELAND, JULY 23, 1936

Members of the Board of Directors American Foundrymen's Association:

We are pleased to submit to you and for the records, the following as a report of the exhibit held in Detroit, May 4-9, 1936. In quality of displays and demonstrations made by exhibitors, and in interest, this event would rank with any of the industrial shows of recent years. Many will be surprised, however, to learn that in the amount of space sold and in the number of exhibitors participating, it ranked seventh among exhibits held in conjunction with our annual conventions. We name them in the order of amount of space used, showing also, number of exhibitors.

Place	Space Occupied (Sq. Ft.)	No. of Exhibitors
Detroit, 1926	81,000	267
Cleveland, 1930	77,400	250
Columbus, 1920	76,600	240
Philadelphia, 1928	75,238	239
Philadelphia, 1919	60,400	212
Syracuse, 1925	57,370	187
Detroit, 1936	55,741	214

This exhibit did not officially open until Tuesday, the second day of the week and continued through until 4 P. M. Saturday, a schedule which we do not believe it would be well to repeat.

There are many objections to opening on Monday, requiring as it does over-time installation labor costs from Saturday noon until Monday morning, and much inconvenience due to closed freight yards, express offices, etc. There are also objections to continuing an exhibit through Saturday.

Looking back over the 24 foundry exhibits I have been privileged to manage in 14 different cities, I am strongly of the opinion that the most satisfactory schedule of dates we have ever had were on the three occasions when we opened exhibits at noon Saturday, continuing through until 10 P. M., closed on Sunday, and opened again Monday morning, continuing through until 5 P. M. Friday.

This Saturday opening serves as a sort of "dress rehearsal" and gives the exhibitor an opportunity to rearrange or make adjustments on Sunday, get rested and ready for the crowd when the convention starts on Monday.

This plan for a Saturday opening and evening session has the advantage of securing local publicity and has very definitely helped to build up attendance at meetings and exhibits during the following week.

In view of the fact that there has been some irregularity, not only in staging exhibits, but in convention dates during the past ten years, it perhaps would be well to review briefly for the information of the present Board members, what our practices and policies have been.

From the first exhibit, which was organized in 1906 and staged in

the Armory in Cleveland, until 1926, when an international convention and exhibit was staged in Detroit, exhibits were held in conjunction with each annual convention of the Association.

At a meeting of the Board of Directors held during the Detroit Congress (held during last week in September) it was our pleasure to recommend for various reasons then set forth that we return to the practice of spring conventions and meet again in May or June, 1927.

As that would provide an interval of only nine months between conventions and realizing that exhibitors had extended themselves in putting on the largest show we had ever staged, it was our further recommendation that the 1927 convention be held without an exhibit.

These recommendations were approved and the convention was held at the Edgewater Beach Hotel in Chicago, the first week of June, 1927 without an exhibit. This meeting was generally voted a successful one, having a registered attendance of 1092. Exhibitor companies were well represented, and many times during the week, these representatives, commenting on the attendance, expressed disappointment that no opportunity was offered for showing their "line" to them, and it was suggested that if we had another such meeting, some provision should be made for sales conference rooms where drawings, photographs, and models could be displayed.

In May, 1928, a large and successful exhibit was staged at Philadelphia with an attentance more than five times greater than that of the 1927 convention.

In 1929, it was decided to meet again at Chicago, with headquarters at the Stevens Hotel. Then prompted by the suggestions that had been made in 1927 that consideration be given to some provision for equipment suppliers and companies, it was voted to hold a so-called limited exhibit in the hotel, limited in the amount of space any one exhibitor would be permitted to use, and as to operations permissible.

This too was a successful event with a registered attendance of more than four times that at the Edgewater Beach Hotel in 1927. A large majority of the 154 exhibitors expressed themselves as well pleased and recommended a program of exhibits of this type on alternate years. In May, 1930, a large and successful exhibit was staged in the Cleveland Auditorium and Annex with a registered attendance of over 7000. Then in 1931, we returned to the Stevens Hotel and staged another limited exhibit with an increase of 14 in the number of exhibitors over 1929.

Continuing with the plan, then quite generally accepted and approved, of holding limited exhibits on odd numbered years and unlimited exhibits on even numbered years, arrangements were made to hold a convention and exhibit in the new Public Auditorium in Philadelphia in the spring of 1932, with the Mechanical Handling Division of the A.S.M.E. cooperating. With the depression continuing and business conditions bad, it was decided as late as February to abandon plans for an exhibit and secure an extension of our lease with the Philadelphia auditorium until May, 1933. We then, on short notice, arranged for a convention without an exhibit at the Hotel Statler in Detroit.

The announcement of this hotel convention resulted in considerable

correspondence with exhibitors and insistence on the part of some that rooms or halls be set aside for displays. It was found that not sufficient space could be had to accommodate all, whereupon, it was decided to make provisions for none. The registered attendance at this meeting was approximately 700.

As we approached 1933, we were again prompted to change our plans and accept the invitation of Chicago to meet in convention there during Engineering Week of the Chicago Century of Progress, and again provision was made for a limited show in the Stevens Hotel. In 1934 our Association was again awarded the privilege of staging another International Foundry Congress, and Philadelphia was selected as the place for a convention and exhibit. To meet the wishes of our overseas guests, this event was held the last week of October, again throwing us off our schedule.

At the Board meeting following the Philadelphia convention, we were confronted with a situation similar to that on the occasion of the International Foundry Congress in 1926. It was decided, however, not to go back to a spring convention until 1936, providing an interval of 19 months; in the meantime, to stage a convention in Toronto in August, 1935 without an exhibit. That brings us up to the convention and exhibit in Detroit which we have just reported on.

From the foregoing, you will see that it is a generally accepted practice that unlimited shows be staged only on even numbered years, and that on odd numbered years, provisions be made for a limited exhibit or staging a convention without exhibits.

No official action has been taken with regard to plans for 1937, and it, therefore, will be a question for the incoming Board to decide the time, place, and character of the 1937 annual meeting. The staging of exhibits is one of our major activities and is to our Technical Department what the advertising pages are to a trade magazine or publication. Even as publications could not produce their interesting "reader" sections and supply their subscribers with their various services on subscriptions alone, likewise exhibits and the income therefrom enable us to carry on a bigger program of activities beneficial to foundrymen as well as to those who supply them with equipment and materials.

We have mentioned that the average attendance at conventions with exhibits is approximately five times greater than at conventions without, and, if it is true that the greater the number attending annual conventions, the greater the benefit to industry as a whole, then, is it not our responsibility to give consideration to a program that will give the maximum attendance, and maximum value to those who attend, being governed at all times, as we have in the past, by conditions as we find them, rather than by any fixed calendar of events?

Respectfully submitted,

C. E. HOYT, *Manager of Exhibits.*

Report of Technical Secretary

ANNUAL MEETING, BOARD OF DIRECTORS

CLEVELAND, JULY 23, 1936

The Technical Department has this past year dealt chiefly with the preparation of the program for the Detroit convention, preparation of the 1935 Bound Volume of TRANSACTIONS, the bi-monthly TRANSACTIONS, and work in connection with the various general interest and divisional committees.

1936 PROGRAM

The program for the Detroit convention was, it is believed, one of the best balanced in interests that has been held. Besides the 5 general interest sessions, each division had 2 or more sessions devoted to papers and reports applying to its branch of the industry.

A total of 32 papers, supplemented by 15 committee reports, were presented.

A total of 24 sessions were held at the Detroit convention, and were divided as follows: Round Table Luncheon Meetings, 3; Shop Operation Course Sessions, 7; Technical Papers Sessions, 14.

Two sessions were scheduled for one evening of the convention. These were exceptionally well attended and leads us to recommend more evening sessions with fewer on the afternoons of convention days.

PUBLICATIONS

Six bi-monthly issues of "*Transactions*," containing bulletin sections, have been issued to all members. These contained 288 pages of bulletin, or news material, and sections of the convention proceedings. The pages for the Bulletin Sections for the past years ran as follows:

Years	Pages
1935-6	288
1934-5	264
1933-4	254

The Bound Volume of "*Transactions*," vol. XLIII, was issued in February 1936, containing 624 pages.

Preprints. Twenty-one (21) Detroit convention papers were preprinted. These contained a total of 376 pages. Those which were ready in time were mailed to all members. Copies of all were available at the meeting halls.

Reprints. During the year special reprints of certain papers were printed and mailed to members. These were the papers on "Dust Hazards and Dust Equipment" as presented at Toronto, and the "Standards for Four-Year Apprenticeship." After the Detroit convention, the papers on "Safety and Hygiene" and the address by Mr. Cameron were reprinted and mailed to all members.

Digests of Current Foundry Literature

During the past year, 32 pages of digests of current foundry litera-

ture have been published in the Bulletin Section of *"Transactions."* These digests were prepared by our staff. Inquiries received as a result of the publication indicate considerable interest. These digests when clipped and filed in our office, provide a source of material for bibliographies on various subjects, requests for which are frequently received.

Cast Metals Handbook

The Cast Metals Handbook, issued this past year, has received praise in editorial comment in the trade and technical press throughout the world and it is believed that it fills a needed place, in presenting under one cover authoritative data on all branches of cast metals products.

The next task ahead of our Association in this work is to issue periodic, improved editions. Each Division has now a sub-committee to review and improve its section. In addition, there is a general policy committee consisting of representatives from all the Divisions.

SECTIONAL MEETINGS

Michigan State College

Approximately 100 foundrymen attended the sectional meeting at East Lansing, Michigan, held February 7, under the joint sponsorship of Michigan State College, the Detroit Chapter, and the A.F.A. This was the fifth in the series which is becoming recognized to be of great interest among the auto casting foundries.

Birmingham Meeting

The 4th annual foundry meeting, held in Birmingham on February 27-28, sponsored by the Birmingham Section of the American Society of Mechanical Engineers, the foundrymen of the District, and the A.F.A., had a record attendance of 400, and resulted in the formation of the Birmingham Chapter of the A.F.A.

Chicago Meeting On Cast Metals

The Association office cooperated extensively in the joint meeting, on March 16, of the Chicago Chapter, The Western Society of Engineers, and the Chicago Section of the A.S.M.E. An evening meeting with two speakers was held, one speaker discussing design factors and one properties of cast metals. The attendance was 500, and the chairman, F. A. Lorenz, Jr., of the American Steel Foundries. An exhibit of castings was also held, some 21 companies showing cast products. This was the third joint meeting of these organizations, and the second castings exhibit.

CHAPTER COOPERATION

Previous to the Toronto convention, four chapters had been formed, these being: Chicago, Northeastern Ohio, Quad City and Metropolitan Philadelphia.

At the Toronto convention, the first annual meeting of chapter officers and representatives was held to discuss chapter policies. The second meeting was held at Detroit convention, by which time the following chapters had been added: Detroit, St. Louis, Birmingham, Milwaukee, and Northern California.

The Canadian Section was organized at the Toronto convention. The Canadian Section proposes to hold the first of its regional meetings this fall or winter. Our office is rendering assistance to the chapters and sections in forming programs and giving publicity.

INTERNATIONAL RELATIONS COMMITTEE

The International Relations Committee, under the chairmanship of Frank Steinebach, has been active in developing arrangements for a party to attend the International Foundry Congress to be held at Düsseldorf, Germany, in September, 1936.

Exchange Papers

Exchange Papers before European Congresses were prepared by H. A. Schwartz for the Belgian meeting, H. H. Judson for the I. B. F. congress, and L. B. Knight, Jr. for the French meeting. Jan Erler has prepared an exchange paper for the Düsseldorf conference. Mr. Judson presented his paper in person. The others were presented by our European representative, V. Delport.

Papers from the I. B. F. and the French Association were presented at our Detroit convention. These exchange papers increased to 80 in number, those which have been presented before A.F.A. meetings, or given by A.F.A. representatives before European meetings since the exchange arrangement was initiated in 1919.

FOUNDRY COST COMMITTEE

The Cost Committee, under the chairmanship of Sam Tour, has representatives from the various metal groups, with official representatives from the Malleable Founders' Society, Steel Founders' Society, and the Gray Iron Founders' Society. Non-ferrous interests are represented by Vice-President Wick and Mr. A. E. Grover.

For several years this committee has had as its function the stimulation of interest in use of standard cost systems of the various trade associations by all foundrymen. It endeavored to secure this interest by holding annual cost sessions and issuing papers. At an open meeting of the committee held at Toronto, it was decided that the immediate program of work would be to prepare charts of the four foundry cost systems to show in simple form the basic fundamentals of these systems and the basic similarities between them.

APPRENTICE TRAINING COMMITTEE

The Apprentice Training Committee, during the past year has been quite active under the chairmanship of John Ploehn. It issued, in cooperation with the N. F. A., a printed pamphlet on "Standards of Four-year Foundry Apprentices." A second activity was the holding of a session at Detroit. This session was better attended than any in the past, the speakers giving exceptionally interesting talks.

A third activity was the reviving of the Apprentice Molding and Pattern Contests, in which apprentices from Detroit, Milwaukee, Quad Cities, Cleveland, Philadelphia, St. Paul and Peoria took part. Nine

prizes were given, three each in Steel Molding, Gray Iron Molding and Pattern Making.

FOUNDRY SAND RESEARCH

The Committee on Foundry Sand Research, under its technical director, Dr. H. Ries, has been very active this past year, having held two general committee meetings and with its subcommittees active through correspondence. Reports submitted for printing during this coming year are: (a) Sea Coal and Organic Binders, (b) Specifications for Sands When Purchased, and (c) A.F.A. Grain Distribution Numbers. This committee is preparing for early release a complete revision of the publication "Standard and Tentative Standards for Testing and Grading Foundry Sands." This will be the fourth edition of this work.

A publication giving a condensed review of foundry sand control is also under preparation, specifically detailing the properties of sand expressed in a practical way and discussing the affect of these properties on foundry work.

Eleven sub-committees are continuing their work on: (1) Grading, (2) Bonding Clays, (3) Strength Tests, (4) Steel Sands and Refractories, (5) Mold Hardness, (6) Durability, (7) Fineness Test, (8) Specifications, (9) Sea Coal and Organic Binders, (10) Sand Pamphlet, (11) High Temperature Properties.

The work of the subcommittees on High Temperature Properties is considered of exceptional importance to all branches of the industry. This work will entail a comprehensive study of strength at high temperatures as well as of the expansion and contraction behavior under heating. To carry on this work, the committee needs a special type of high temperature furnace and the time of a research assistant to make the tests. The committee believes that funds for this work can be raised by the Association from interested firms, as some have already expressed their willingness to contribute.

REPRESENTATIVES ON SECTIONAL COMMITTEES

This association has representatives on 15 committees of the A.S.A. The most active of these committees this past year being that on Safety Code for Exhaust Systems, J. R. Allan, representative and O. E. Mount, alternate. The work of this committee has been carefully watched by Mr. Allan, who is now chairman of the A.F.A. committee on Industrial Hygiene Codes.

An Advisory Committee on Mechanical Standards has recently been set up with L. M. Sherwin, Brown & Sharpe Mfg. Co., Providence, R. I., as our representative.

Each Division has representation on the committees of the American Society for Testing Materials in which it has interest, and our Association through our Division representatives, cooperates with the A.S.T.M. in the forming of specifications for cast metals. This form of cooperation was approved by a joint committee of the two associations in 1922.

DIVISION ACTIVITIES

Steel Division

Under the direction of Chairman P. E. McKinney, the work of the Steel Division Committees has been reorganized in a very effective manner. The active committees function under an executive committee consisting of the chairmen of active committees, and some 6 appointed members. The active committees at present are those on: (1) Program—Chairman, Jerome Strauss; (2) Methods of Producing Steel for Castings—Chairman, F. A. Melmoth; (3) Test Coupons—Chairman, J. M. Sampson; (4) Radiography—Chairman, C. W. Briggs; (5) Handbook Revision—Chairman, R. A. Bull; (6) Design of Steel Castings—Chairman, John Locke.

Gray Iron Division

The principal activity of the Gray Iron Division this past year has been in the preparation of a summary of Alloy Cast Iron, which, when finished, will be incorporated as a portion of the Cast Metals Handbook. Three sections of this report were presented for discussion at Detroit, these sections being on: Specific Applications, Heat Treatment, and Foundry Practice.

The schedule calls for the completion of this work this year, and when finished, the committee recommends that it be first published as a separate booklet, later incorporating the bulk of the material in the Handbook.

Three new committees have been added to the Division line-up. These are: Committee on Handbook Revision, Committee on Welding Cast Iron, and Committee on Cooperation with Engineering Schools.

Malleable Division

The Malleable Division at Detroit had one of its best programs, holding two formal sessions and one round table meeting under the chairmanship of Ralph Teeter. The Division has been ably represented on the A.S.T.M. Committee A-7 on Malleable Cast Iron by H. A. Schwartz, who secured the recognition by the Division's definition for Pearlitic Malleable.

For its 1937 program, the Division is to devote its efforts to securing papers for three symposia, one on Shrinkage, one on Sand Control and one on Melting Furnaces.

Non-Ferrous Division

At the Detroit convention, H. M. St. John, Detroit Lubricator Co., was elected chairman of the Non-ferrous Division to serve for two years. Harold J. Roast of the Canadian Bronze Co., Montreal, was elected vice-chairman for two years.

This Division has for the past year had a definite program of developing recommended practices for the various standard alloys as outlined in the Cast Metals Handbook. These recommended practices cover Molding, Melting, Sands, etc. The first issued was at Toronto on Aluminum Alloys, the second at Detroit on Magnesium Alloys. Three others covering Sand Cast High Lead Bronze, Brass and Valve Bronze, and

Manganese Bronze have been submitted for review. Others are in the process of development.

The Program Committee is now cooperating with the Recommended Practice Committee by securing papers which will present data for the practices. This whole effort is of direct interest to practical foundrymen and the practices, when completed, will make an excellent book for the non-ferrous foundrymen.

Another committee of the Division is working on a report on Analyses of Defects. The Program Committee for 1937 plans two symposiums: on Sand Control, and High Tensile Alloys, with a possible third on Heat Treatable Alloys.

The Division has also a committee on Handbook Revision, which has made certain recommendations to the General Policy Committee.

COMMITTEE MEMBERSHIP

Our Association now has some 275 members who are active, either as officers, members of Association committees, or as representatives of the Association on committees of other associations. In addition, there are approximately 150 others who are serving as Chapter officers or committeemen.

This group of workers, which is constantly increasing in number, makes of the Association a powerful force for the good of the industry, if properly directed and led. To these men and their predecessors goes much of the credit for the developments made by the foundry industry.

Respectfully submitted,

R. E. KENNEDY, *Technical Secretary.*

Summary of Proceedings of the 40th Annual Meeting

The Fortieth Annual Convention of the American Foundrymen's Association was held in Detroit, Mich., May 4 to 9, 1936. A Foundry and Allied Industries Exposition was held in conjunction with the Convention, under the auspices of A.F.A. Many of the 5,500 attending pronounced the Convention and Exposition the largest and best in the history of the Association both from the view point of the excellence of the technical papers presented and from the size, design and diversity of the over 220 exhibits.

That this was true is evidenced by the large volume of publicity the Industry received, both locally and nationally. The general tenor of the statements by the technical press is typified by the following extract from a well-known trade paper: "The Foundry Industry is all set to go places. We cannot recall a time when the morale of foundrymen was keyed to a higher pitch. They set out to make the 1936 meeting and show a monument to the post-depression rebirth of the industry. They succeeded beyond expectations."

During the past few years, many comments have been received on the earnestness and enthusiasm shown at the technical sessions. This year was no exception and the same feelings prevaded throughout the meetings. A total of 16 sessions was held this year. Although this is less than in the past, it was felt that by limiting the number of sessions, members would have more time to spend at the exhibits. Few sessions were held in the afternoon and none on Saturday. This latter day was designated as Detroit Day, the exhibit being held open for the benefit of local foundrymen who were unable to attend during the week. Two sessions were held Wednesday evening and, although other meetings were very well attended, these sessions were the best attended of any of those held.

Of the 16 sessions held, three were on Cast Iron; two each on Malleable, Steel and Non-Ferrous Founding; one each on Sand Research, Apprentice Training, Refractories and Safety and Hygiene; four Round Table Conferences, one each on Malleable, Non-Ferrous and Steel practice and the fourth was a Foundry Instructors luncheon. Two shop courses were held. One, of four sessions, was devoted to Cast Iron and the other, of three sessions, to Sand Control. A total of 32 papers was presented together

with many committee reports. In addition, approximately 25 committee meetings were held, all of which were well attended indicating a revival of interest in committee work.

Two exchange papers were presented this year, one on behalf of the Institute of British Foundrymen and the other from the Association Technique de Fonderie de France, the French Foundry Technical Association.

Outstanding among the technical sessions were those on Apprentice Training, Safety and Hygiene in the Foundry, and Alloy Cast Iron. The session on Apprentice Training was the best session on that subject ever held and indicated a wide-spread interest. The session on Safety and Hygiene, held under the auspices of the Safety and Hygiene Section of A.F.A., was addressed by experts on the medical, legislative and engineering aspects of the subject. The Alloy Cast Iron session reviewed and discussed several sections of the book on Alloy Cast Iron which a committee of that designation is preparing.

Plant visitations were exceptionally popular this year. Although Monday, May 4, was designated as the day for this activity, visitations continued with undiminished interest throughout the week. The popularity of this section of the program was so great that in many instances the facilities were taxed to the utmost to take care of the demand. As an example, over 400 foundrymen signed for the organized visit to the foundry of the Ford Motor Company on Monday.

The visiting ladies were most cordially entertained throughout Convention Week with teas, shopping tours and trips to points of interest in and around Detroit by the Ladies Entertainment Committee of the Detroit Convention Committee. This committee was under the general chairmanship of J. L. MAHON, American Car & Foundry Co.

The Detroit Convention Committee is to be congratulated on the excellent manner in which it assisted in staging the Fortieth Annual Convention—Foundry and Allied Industries Exposition and much of the success of that event is due to its splendid cooperation. The Detroit Convention Committee was under the general chairmanship of VAUGHAN REID, City Pattern Works, Detroit, who was also Chairman of the Detroit Chapter of A.F.A.

A summary of the various sessions follows:

CAST IRON SHOP COURSE (Session 1)

Tuesday, May 5, 9:00 A. M.

Chairman—P. T. Bancroft, Moline, Ill.

Discussion Leader—E. J. Carmody, Campbell, Wyant & Cannon Foundry Co., Muskegon, Mich.

Subject—Cupola Operation and Repair.

OPENING SESSION

Tuesday, May 5, 10:00 A. M.

Presiding: D. M. Avey, President of the American Foundrymen's Association and Vice President James L. Wick, Jr.

President Avey, after announcing the formal convening of the Fortieth Annual Convention, introduced Mr. Smith, President of the Common Council of the City of Detroit, and Harvey Campbell, Detroit Chamber of Commerce, who gave short addresses of welcome to the assembled members and guests of the Association. President Avey responded on behalf of the Association.

With Vice President Wick in the chair, President Avey then presented the annual presidential address.

The next order of business was the appointment of a committee of three to nominate a committee to be voted upon at the Annual Business Meeting which, together with the three last past presidents, would serve as the 1937 Nominating Committee. The three members appointed were Jerome Strauss, Vanadium Corp. of America, Bridgeville, Pa.; A. L. Boegehold, General Motors Corp., Detroit; and H. W. Johnson, Greenlee Foundry Co., Chicago.

Following several announcements on various Convention events, the meeting adjourned.

NON-FERROUS CASTING PRACTICE

Tuesday, May 5, 11:00 A. M.

Chairman—Jerome Strauss, Vanadium Corp. of America, Bridgeville, Pa.

Vice Chairman—John W. Bolton, Lunkenheimer Co., Cincinnati, Ohio.

The following papers were presented and discussed:

Manganese Bronze—A Correlated Abstract, by F. R. Hensel, P. R. Mallory Co., Indianapolis, Ind. In absence of the author, this paper was presented by Vaughan Reid, Jr., City Pattern Works, Detroit.

Pressure Castings in Aluminum Bronzes, by M. T. Ganzauge, Goulds Pumps, Inc., Seneca Falls, N. Y.

At the Annual Business Meeting of the Non-Ferrous Division, H. M. St. John, Detroit Lubricator Co., Detroit, was elected Chairman of the Division and Harold J. Roast, Canadian Bronze Co., Ltd., Montreal, P. Q., Canada, Vice Chairman. These officers serve for two years. The following were elected members of the Advisory Committee to serve for 4 years: J. J. Curran, Walworth Co., Greensburg, Pa.; David M. Curry, Interna-

tional Nickel Co., Inc., New York; John H. Diedrich, Blackhawk Foundry & Machine Co., Davenport, Iowa; and Wm. J. Laird, Westinghouse Electric & Mfg. Co., Lenhardt Plant, Pittsburgh, Pa.

Following the election, reports of various Division committees on the past year's activities were presented.

MALLEABLE CAST IRON

Tuesday, May 5, 11:00 A. M.

Chairman—P. C. DeBruyne, Moline Malleable Iron Co., St. Charles, Ill.

The following paper was presented and discussed:

Molding Sand in the Malleable Foundry, by H. W. Dietert and F. Valtier, H. W. Dietert Co., Detroit. The paper was presented by Mr. Dietert.

ENGINEERING INSTRUCTORS ROUND TABLE LUNCHEON

Tuesday, May 5, 12:30 P. M.

Chairman—C. J. Freund, Dean of Engineering, University of Detroit, Detroit.

Discussion centered around ways and means of getting information on cast metals before engineering students.

SAND RESEARCH

Tuesday, May 5, 2:00 P. M.

Chairman—R. F. Harrington, Hunt-Spiller Mfg. Co., Boston, Mass.

Vice Chairman—W. G. Reichert, Singer Mfg. Co., Elizabeth, N. J.

The following papers were presented and discussed:

The Constitution of Bonding Clays and Its Influence on Bond Property, by R. E. Grim, R. H. Bray and W. F. Bradley, Illinois State Geological Survey, Urbana, Ill. Presented by Mr. Grim.

Deformation and Resilience of Molding Sand, by H. W. Dietert and R. A. Dietert, H. W. Dietert Co., Detroit. Presented by H. W. Dietert.

Practical Sand Control in Gray Iron Foundries, by H. A. Deane, Deere & Co., Moline, Ill.

Foundry Sand Testing Problems at High Temperatures, by P. E. Kyle, Massachusetts Institute of Technology, Boston, Mass.

Following the presentation and discussion of these papers, a report on the various committees of the Foundry Sand Research Committee were presented by Dr. H. Ries, Technical Director of the committee.

SAND CONTROL SHOP COURSE (Session 1)

Tuesday, May 5, 4:00 P. M.

Chairman—G. P. Phillips, International Harvester Co., Chicago, Ill.

Discussion Leader—W. G. Reichert, Singer Mfg. Co., Elizabeth, N. J.

Subject—Molding Sand for Light Gray Iron Castings.

JOINT STAG DINNER AND SMOKER

Tuesday, May 5, 7:00 P. M.

This event, a great success with approximately 1,150 attending, was sponsored jointly by the Foundry Equipment Manufacturers Association, Detroit Chapter of A.F.A. and the American Foundrymen's Association. H. S. Simpson, National Engineering Co., Chicago, was chairman of the committee which staged the event.

CAST IRON SHOP COURSE (Session 2)

Wednesday, May 6, 9:00 A. M.

Chairman—P. T. Bancroft, Moline, Ill.

Discussion Leader—Fred J. Walls, International Nickel Co., Inc., New York.

Subject—Fundamentals in Welding Cast Iron.

CAST IRON

Wednesday, May 6, 10:00 A. M.

Chairman—M. Kuniansky, Lynchburg Foundry Co., Lynchburg, Va.

Vice Chairman—V. A. Crosby, Climax Molybdenum Co., Detroit.

The following papers were presented and discussed:

Control of Manganese in the Cupola, by M. T. Davis, III, General Electric Co., Ontario, Calif. In absence of the author, this paper was presented by M. F. Surls, Michigan State College, East Lansing, Mich.

Determining the Height of Molten Metal in the Cupola, by Carl Harmon, Chevrolet Motor Co., Saginaw, Mich.

Effects of Coke Below Tuyeres, by H. V. Johnson and Dr. T. J. MacKenzie, American Cast Iron Pipe Co., Birmingham, Ala. Presented by Dr. MacKenzie.

MALLEABLE CAST IRON

Wednesday, May 6, 10:00 A. M.

Chairman—F. L. Wolf, Ohio Brass Co., Mansfield, Ohio.

Vice Chairman—L. N. Shannon, Stockham Pipe Fittings Co., Birmingham, Ala.

The following papers were presented and discussed:

Metallographic Changes During Cooling Between First and Second Stages of Annealing, by Dr. H. A. Schwartz and C. H. Junge, National Malleable & Steel Castings Co., Cleveland, Ohio.

Measuring and Controlling Pouring Temperatures, by Carl F. Joseph, Saginaw Malleable Iron Division, General Motors Corp., Saginaw, Mich.

Selection of Melting Furnaces for Malleable Iron, by N. G. Girshovitch and A. F. Landa, Central Institute for Scientific Research for Machine Construction, U. S. S. R. In absence of the authors, the paper was presented by E. Touceda, Malleable Iron Research Institute, Cleveland, Ohio.

The report of the Malleable Division Committee on Specifications reported at this meeting. The report was presented by Dr. H. A. Schwartz.

MALLEABLE DIVISION ROUND TABLE LUNCHEON

Wednesday, May 6, 12:30 P. M.

Chairman—R. J. Teetor, Cadillac Malleable Iron Co., Cadillac, Mich.

This meeting was a general discussion on malleable cast iron practice. Such subjects as shrinkage, gating and risering, pattern equipment, design, melting problems were discussed.

NON-FERROUS DIVISION ROUND TABLE LUNCHEON

Wednesday, May 6, 12:30 P. M.

Chairman—T. C. Watts, Falcon Bronze Co., Youngstown, Ohio.

Vice Chairmen—Harold J. Roast, Canadian Bronze Co., Ltd., Montreal, P. Q., Canada and H. J. Rowe, Aluminum Co. of America, Cleveland, Ohio.

Such topics as furnace operation, atmosphere and insulation, relation between deoxidizer content, gates, risers, pouring temperature, shrinkage and sand attack; in addition to questions on the papers presented at the various non-ferrous sessions and how the Cast Metals Handbook can be made more helpful were discussed.

APPRENTICE TRAINING

Wednesday, May 6, 2:00 P. M.

Chairman—S. Wells Utley, Detroit Steel Casting Co., Detroit, Mich.

The following papers were presented and discussed:

Apprenticeship, by Franklin R. Hoadley, Farrel-Birmingham Co., Ansonia, Conn.

Apprentice Training in Detroit Industries, by H. W. Boulton, Murray Corp., Detroit, Mich.

Training Foundry Apprentices in Cleveland, by James G. Goldie, Cleveland Trade School, Cleveland, Ohio.

SAND CONTROL SHOP COURSE (Session 2)

Wednesday, May 6, 4:00 P. M.

Chairman—D. L. Yost, Budd Wheel Co., Detroit, Mich.

Discussion Leader—A. S. Wright, Hunt-Spiller Mfg. Co., Boston, Mass.

Subject—Molding Sand for Medium and Heavy Gray Iron Castings.

FOUNDRY REFRACTORIES

Wednesday, May 6, 8:00 P. M.

Chairman—C. E. Bales, Ironton Fire Brick Co., Ironton, Ohio.

Vice Chairman—A. H. Dierker, Engineering Experiment Station, Ohio State University, Columbus, Ohio.

The following papers were presented and discussed:

Behavior of Cupola Refractories under Severe Operating Conditions, by John Lowe, Campbell, Wyant & Cannon Foundry Co., Muskegon, Mich.

Notes on Some Foundry Refractories, by J. D. Sullivan, Battelle Memorial Institute, Columbus, Ohio.

Overcoming Spout Trouble by Use of a Monolithic Refractory Tile Trough, by J. A. Bowers, American Cast Iron Pipe Co., Birmingham, Ala., and Charles Green, Alabama Clay Products Co., Birmingham, Ala. Presented by Mr. Bowers.

Following the presentation and discussion of these papers, an open forum was held on insulated ladles followed by many questions on cupola operation and refractory service.

STEEL FOUNDING

Wednesday, May 6, 8:00 P. M.

Chairman—John Howe Hall, Taylor-Wharton Iron & Steel Co., High Bridge, N. J.

The following papers were presented and discussed:

Cleaning Steel Castings, by Paul Dougher, American Steel Foundries, East Chicago, Ind.

Industrial Propane for Flame Cutting and General Foundry Fuel Use, by F. H. Andrews and E. A. Jamison, Phillips Petroleum Co., Philadelphia, Pa.

George Batty, Consultant on Steel Castings, Drexel Hill, Pa., presented a discussion on Scaling of Steel Castings.

A report of the Representative on A.S.T.M. Committee on Specifications was presented by R. A. Bull, Consultant on Steel Castings, Chicago, Ill., for A.F.A. Representative E. W. Campion, Bonney-Floyd Co., Columbus, Ohio.

CAST IRON SHOP COURSE (Session 3)

Thursday, May 7, 9:00 A. M.

Chairman—Leslie G. Korte, Atlas Foundry Co., Detroit, Mich.

Discussion Leader—G. P. Phillips, International Harvester Co., Chicago.

Subject—Alloys—Why Used and What They Do to Cast Iron.

CAST IRON

Thursday, May 7, 10:00 A. M.

Chairman—Dr. J. T. MacKenzie, American Cast Iron Pipe Co., Birmingham, Ala.

Vice Chairman—E. K. Smith, Electro Metallurgical Co., Detroit, Mich.

The following papers were presented and discussed:

Notes on Fatigue Properties of Alloy Cast Iron, by H. L. Daasch, Iowa State College, Ames, Iowa. In absence of the author, the paper was presented by J. W. Bolton, Lunkenheimer Co., Cincinnati, Ohio.

Heat Treatment of Cast Iron by Hardening and Tempering, by J. E. Hurst, Sheepbridge Stokes Centrifugal Castings Co., Ltd., Chesterfield and Bradley and Foster, Ltd., Darleston, England, and President of the Institute of British Foundrymen. In absence of the author, the paper was

presented by G. P. Phillips, International Harvester Co., Chicago, Ill. This was the exchange paper of Institute of British Foundrymen.

Some Applications of Heat Treated Cast Irons in France, by M. Ballay and R. Chavy, Paris, France. Exchange Paper of Association Technique de Fonderie de France, the French Foundry Technical Association. In absence of the authors, this paper was presented by R. F. Harrington, Hunt-Spiller Mfg. Co., Boston, Mass.

NON-FERROUS CASTINGS

Thursday, May 7, 10:00 A. M.

Chairman—H. M. St. John, Detroit Lubricator Co., Detroit, Mich.

Vice Chairman—T. E. Kihlgren, International Nickel Co., Inc., Bayonne, N. J.

The following papers were presented and discussed:

Founding Aluminum Bronzes, by J. E. Crown, Naval Gun Factory, Washington, D. C. In absence of the author, the paper was presented by his associate, E. J. Bush, Naval Gun Factory.

Sand Castings of the Copper-Silicon Alloys, by H. A. Bedworth and V. P. Weaver, American Brass Co., Waterbury, Conn. Presented by Mr. Bedworth.

The Committee on Recommended Practices presented the second of a series of Recommended Practices on sand cast magnesium alloys. The report was presented by H. J. Rowe, Aluminum Co. of America, Cleveland, Ohio.

STEEL DIVISION ROUND TABLE LUNCHEON

Thursday, May 7, 12:30 P. M.

Chairman—A. H. Jameson, Malleable Iron Fittings Co., Branford, Conn.

Such subjects as metal penetration into the face of the mold, relative merits of the several methods of making steel, effect of aluminum as a deoxidizing agent and solidification problems were discussed.

ANNUAL BUSINESS MEETING

Thursday, May 7, 3:30 P. M.

President D. M. Avey Presiding

Officers reports were given and new officers elected. Executive Secretary-Treasurer C. E. Hoyt submitted a brief report on the condition of the Association.

The 1936 Nominating Committee report was read by the secretary. Personnel of this committee was as follows:

Past President E. H. Ballard, General Electric Co., West Lynn, Mass.

Past President T. S. Hammond, Whiting Corp., Harvey, Ill.

Past President Frank J. Lanahan, Fort Pitt Malleable Iron Co., Pittsburgh, Pa.

Dr. G. H. Clamer, Ajax Metal Co., Philadelphia, Pa.

A. E. Hageboeck, Frank Foundries Corp., Moline, Ill.

H. A. Schwartz, National Malleable & Steel Castings Co., Cleveland, Ohio.

A. E. Walcher, American Steel Foundries, Chicago, Ill.

The Nominating Committee presented the names of the following members for officers and directors:

For President To Serve for One Year

James L. Wick, Jr., Falcon Bronze Co., Youngstown, Ohio.

For Vice President To Serve for One Year

H. Bornstein, Deere & Co., Moline, Ill.

For Directors To Serve for Three Years Each

James R. Allan, International Harvester Co., Chicago, Ill.

D. M. Avey, *The Foundry*, Penton Bldg., Cleveland, Ohio.

Carl C. Gibbs, National Malleable & Steel Castings Co., Cleveland, Ohio.

Marshall Post, Birdsboro Steel Foundry & Machine Co., Birdsboro, Pa.

L. N. Shannon, Stockham Pipe Fittings Co., Birmingham, Ala.

Following the presentation of this report, a motion was made, seconded and unanimously approved that the secretary cast the ballot of the Association for those nominated.

Upon a motion, duly seconded and unanimously approved, Retiring President D. M. Avey and 1936 J. H. Whiting Gold Medalist David McLain were elected to Honorary Life Membership in the Association. Dr. H. Ries, 1936 Joseph S. Seaman Gold Medalist, had been so honored in 1924.

The next report presented was that of the committee appointed by the president to nominate members for the 1937 Nominating Committee. The report of the committee, read by John W. Bolton, Lunkenheimer Co., Cincinnati, Ohio, nominated the following as members of the 1937 Nominating Committee:

J. H. Locke, General Steel Castings Corp., Eddystone, Pa.

G. P. Phillips, International Harvester Co., Chicago, Ill.

H. J. Roast, Roast Laboratories, Montreal, P. Q., Canada.

R. Schniedewind, University of Michigan, Ann Arbor, Mich.

and as Alternate members:

R. L. Binney, Binney Castings Co., Toledo, Ohio.

P. E. McKinney, Bethlehem Steel Co., Bethlehem, Pa.

Frank M. Robbins, Ross-Meehan Foundries, Inc., Chattanooga, Tenn.

W. H. Rother, Buffalo Foundry & Machine Co., Buffalo, N. Y.

On motion made, seconded and unanimously approved, the report of the committee was accepted and the members and alternates of the 1937 Nominating Committee elected.

President Avey then called on Frank G. Steinebach, Chairman, Committee on International Relations, who read greetings from the Association Technique de Fonderie de France, the French Foundry Technical Association. Mr. Steinebach then introduced Prof. Dr. Aulich, official representa-

tive of the German foundrymen's associations, which are sponsoring the Sixth International Foundry Congress in Dusseldorf, Germany, who extended a cordial invitation for members of the American Foundrymen's Association to participate in this event.

W. L. Seelbach, Forest City Foundries Co., Cleveland, Ohio, referring to the recommendations contained in the secretary's report, moved that the President be instructed to appoint a committee of five, one for each branch of the castings industry and one for the foundry equipment industry, to consider suggestions and recommendations on Association policies and activities. The motion was seconded by E. H. Ballard, General Electric Co., West Lynn, Mass., and unanimously carried.

President Avey later named the following as members of this special Policies and Activities Committee:

Frank J. Lanahan, Chairman and representing the Malleable Castings Industry.

James L. Wick, Jr., for the Non-Ferrous Industry.

W. L. Seelbach, for the Gray Iron Industry.

L. S. Peregoy, for the Steel Castings Industry.

H. S. Simpson, for the Equipment and Supply Industry.

Following a few announcements, there being no further business, the meeting adjourned.

SAND CONTROL SHOP COURSE (Session 3)

Thursday, May 7, 4:00 P. M.

Chairman—George Batty, Drexel Hill, Pa.
Discussion Leader—D. D. Cameron, Pratt & Letchworth, Buffalo, N. Y.
Subject—Molding Sand for Steel Castings.

ANNUAL DINNER

Thursday, May 7, 7:00 P. M.

The Annual Dinner was the most successful ever held in the history of the Association with over 600 in attendance. W. J. Cameron,* Ford Motor Co., Detroit, delivered the principal address of the evening which was broadcast over the Columbia Broadcasting System. Mr. Cameron was introduced by Truman Bradley, announcer for Mr. Cameron on the Ford Company program on the CBS.

Following the address, Past President Frank J. Lanahan, Chairman of the Board of Awards, presented Dr. H. Ries, Cornell University, Ithaca, N. Y., with the Joseph S. Seaman Gold Medal of A.F.A. for his outstanding work on foundry sands and David McLain, McLain System, Inc., Milwaukee, Wis., with the J. H. Whiting Gold Medal of A.F.A., for his pioneer work in the use of steel scrap in the cupola and in promoting better furnace practice.

* Copies of Mr. Cameron's address may be obtained by addressing the offices of the Association, 222 W. Adams St., Chicago, Ill.

CAST IRON SHOP COURSE (Session 4)

Friday, May 8, 9:00 A. M.

Chairman—John Grennan, University of Michigan, Ann Arbor, Mich.

Discussion Leader—James H. Lansing, Massey-Harris Co., Inc., Batavia, N. Y.

Subject—Use of Pulverized-Coal-Fired Rotary Furnaces in Melting Cast Iron.

STEEL FOUNDING

Friday, May 8, 10:00 A. M.

Chairman—Major R. A. Bull, Consultant on Steel Castings, Chicago, Ill.

The following paper was presented and discussed:

Studies on the Solidification and Contraction in Steel Castings—IV—The Free and Hindered Contraction of Alloy Cast Steels, by C. W. Briggs and R. A. Gezelius, Naval Research Laboratory, Washington, D. C. Presented by Mr. Briggs.

The following committee reports were received and discussed:

Report of Committee on Methods of Manufacture of Liquid Steel for Castings. Presented by Chairman F. A. Melmoth, Detroit Steel Casting Co., Detroit, Mich.

Report of Representative on Committee on Foundry Sand Research, by R. E. Aptekar, Ass't General Superintendent of Foundries, American Brake Shoe & Foundry Co., New York, N. Y.

Report of Committee on Test Coupons. Presented by Chairman J. M. Sampson, General Electric Co., Schenectady, N. Y.

Report of Committee on Radiography. Presented by Chairman C. W. Briggs, Naval Research Laboratory, Washington, D. C.

Report of Representative on Joint Committee on Effects of Phosphorus and Sulphur in Steel. Presented by Major R. A. Bull.

CAST IRON

Friday, May 8, 10:00 A. M.

Chairman—H. Bornstein, Deere & Co., Moline, Ill.

Vice Chairman—A. L. Boegehold, General Motors Corp., Detroit, Mich.

The following paper was presented and discussed:

Copper and Copper-Manganese Gray Cast Iron, by L. W. Eastwood, C. T. Eddy and A. E. Bousu, Michigan School of Mines and Technology, Houghton, Mich. Presented by Mr. Eastwood.

Reports of the following subcommittees of the Committee on Alloy Cast Iron were received and discussed:

Report of Committee on Foundry Practice

Report of Committee on Specific Applications

Report of Committee on Heat Treatment.

SAFETY AND HYGIENE

Friday, May 8, 1:30 P. M.

Chairman—D. M. Avey, President of A.F.A.

Subject—Progress of Medical, Legislative and Engineering Aspects of Safety and Hygiene in the Foundry.

Report of A.F.A. Committee on Industrial Hygiene Codes. Presented by Chairman James R. Allan, International Harvester Co., Chicago, Ill.

Discussion of Medical Aspects, by Dr. R. R. Jones, Passed Assistant Surgeon, U. S. Public Health Service, Washington, D. C.

Discussion of Legislative Aspects, by Voyta Wrabetz, Chairman of Industrial Commission of Wisconsin.

Open Forum—Forum Leader, Dr. J. A. Britton, Chief Surgeon, International Harvester Co., Chicago, Ill.

Studies on the Solidification and Contraction in Steel Castings—IV—The Free and Hindered Contraction of Alloy Cast Steels*

By C. W. Briggs† and R. A. Gezelius†, Washington, D. C.

Abstract

This paper is the fourth presented by the authors before this Association on solidification and contraction in steel castings. Studies are continued on the free and hindered contraction of cast steel. The contraction characteristics were obtained on eleven alloy steels whose carbon contents were similar. The contraction is hindered by means of springs, and the resulting stresses and the amount of contraction correlated. Experimentation showed that the total contraction of the alloy steels was similar to that of a plain carbon steel.

1. A study of the contraction taking place in the cooling of steel castings from the solidifying temperature of the steel to room temperature was first made by Körber and Schitzkowski[1]. Their data, however, were rather incomplete since various observations seem to indicate that changes in the carbon content of cast steel are responsible for variations in the linear contraction.

2. In the second publication of the series[2], a study was made of the free and hindered contraction of cast steels of varying carbon contents. The following principles of a fundamental nature were disclosed by the data:

a. The total amount of free contraction of cast carbon steel decreases as the carbon content of the steel increases. The

* Published by permission of the Navy Department.

† Metallurgist, and Assistant Metallurgist respectively, U. S. Naval Research Laboratory.

[1] Körber, F. and Schitzkowski G., *"Beitrag zur Schwindung von Stahlguss"*, Stahl und Eisen, p. 129 (1928).

[2] Briggs, C., and Gezelius, R., *"Studies on the Solidification and Contraction in Steel Castings II—Free and Hindered Contraction of Cast Carbon Steel,"* Trans. A.F.A., vol. 42, pp. 449-476 (1934).

Note: This paper was presented at a session on Steel Founding at the 1936 Convention of A.F.A. in Detroit, Mich.

contraction varies from 2.47 per cent for 0.08 per cent to 2.18 per cent for 0.90 per cent carbon steel.

b. The total amount of contraction occurring while cooling to the critical range, in the case of the freely contracting bar, decreases as the carbon content of the steel increases.

c. The amounts of contraction obtained after the freely contracting bars have passed through the critical range are approximately equal.

d. In the cases of the freely contracting bars and the bars hindered slightly while contracting, the carbon content influences the rate of contraction markedly until the bars have contracted approximately 0.10 per cent.

e. Bars hindered while cooling, contract similarly to the freely contracting bars in that, at any temperature prior to the critical range, the amounts of contraction increase with decreasing carbon contents.

f. The total amounts of hindered contraction increase as the carbon content increases.

g. The percentage of the total contraction occurring before the critical range is reached decreases as the tension restraining the bar increases.

h. The data obtained, when the contraction was hindered by the lightest spring, represent approximately the stresses encountered by the average commercial casting as the total contraction under this tension approximates the "pattern-maker's shrinkage" of 3/16 in. per ft.

i. Slight variations from the normal manganese or silicon content of cast carbon steel do not result in measurable differences in the rate of the total amount of free or hindered contraction.

j. The contraction taking place upon the solidification of cast steel, as approximated from the data available at present, is 2.7 per cent.

k. The rate of contraction, as well as the strength of the steel, may influence the formation of hot tears in steel castings.

3. The data thus pointed out that, by varying the carbon content, different amounts of contraction could be obtained. Since the carbon content was so influential in bringing about changes in contraction, it appeared likely that alloy additions would also change the characteristics of free and hindered contraction. Also, various

conflicting opinions as to the effect of alloying elements upon contraction have been presented by members of commercial organizations, thereby pointing out the need for basic information on this subject.

4. In planning the research on contraction of cast alloy steels, it was deemed necessary to maintain the carbon content at approximately the same percentage in all of the alloys studied. This was necessary to ascertain the effect of the alloy additions. Thus, the chemical analyses of the cast steels studied may differ slightly from those usually employed by the industry. It was planned, however, to use alloy additions comparable to those found in commercial practice.

5. Several prominent steel founders were solicited with regard to typical compositions and from their replies a set of 11 alloy cast steels was prepared, studied, and compared with the contraction of the standard carbon cast steel. The carbon content chosen as a standard was 0.35 per cent. This figure was adopted since a large number of commercial cast steels call for a carbon content of 0.35 per cent and a cast carbon steel had already been studied with this amount of carbon present. The manganese and silicon were maintained at approximately 0.75 per cent and 0.35 per cent, respectively, unless they were being used in the capacity of an alloy. The phosphorus and sulphur were kept below 0.04 per cent.

Method Used in Testing

6. The procedure used in collecting the data on the free and the hindered contraction of alloy cast steels was similar to that employed in obtaining the data on plain carbon cast steels.

Bar Design

7. The bar that was used in this study has large ends and a small central section fed by a horn gate, as it was deemed necessary to have a bar that cooled uniformly along its axis. The bars, as cast, were 26 in. long with a diameter at the center of $1\frac{9}{16}$ in. (a cross-sectional area of 2 sq. in.) and a diameter at the ends of $2\frac{1}{4}$ in. Sections $1\frac{3}{4}$ in. in diameter and 2 in. long, which acted as clamps on the stainless steel bolts, were at the ends of the bar and cast integrally with it.

Type of Sand

8. The sand used was a synthetic green sand made up with

No. 40 washed silica sand as a base and mixed in the following propositions by volume:

500 parts silica and
19 parts Bentonite
1 part Cereal Binder
5 per cent water (by weight)

The mixture was mulled for 5 minutes and the following properties were obtained:

Permeability	180 cc. per min.
Compression Strength	3.5 lb. per sq. in.
Shear Strength	nil
Tensile Strength	nil

9. The sand was reclaimed after it had been used. The properties of the reclaimed sand were approximately the same as those of a newly prepared sand.

Molding Procedure

10. Steel flasks 36-in. long and 10-in. wide were constructed of 5-in. channel iron and used as the mold containers. The sand was rammed lightly to a mold hardness number of about 50. A horn gate varying from 2 to ¾ in. in diameter was used for the pouring gate. The ¾-in. section, where the steel enters the mold cavity, was much smaller than the contraction bar at this point and hence froze before the bar, permitting no feeding during the solidification of the bar.

11. A relieving block 1½ in. square, shaped similarly to the horn gate, was molded a short distance away from the horn gate. This block was removed from the mold and, when the hindered bars contracted, the horn gate was able to move freely without being restricted by the molding sand. The surface of the mold cavity was not covered with a mold wash.

Assembling the Mold

12. A stainless steel bolt was placed in each end of the flask. One bolt tied the bar down to the flask and the other was fastened to the flat steel spring. The bolts were ⅞-in. in diameter and had a shank of 4 in. and a body of 5 in. Two grooves ⅜-in. wide and ⅛-in. deep were machined in the body end of the bolt. This permitted the metal, upon solidifying around the bolts, to have a

strong grip on them. The chilling action was so great that the bolts did not fuse into the cast metal.

13. A small quartz thermocouple protecting tube was run through the cope of the mold 1½-in. from the end of the bolt that tied the cast bar down to the flask. This tube extended to the axis of the bar and the readings obtained by the platinum and platinum-rhodium thermocouple represented the temperature of the bar throughout the central 26 in.

14. The flat springs used were made from heat-treated spring steel, 2-in. by 10½-in. with the following thicknesses:

Spring No.	Thickness, in.
"C"	7/8
"G"	9/16
"E"	3/8

The springs were calibrated very carefully in lb., total load.

15. Ames dials, held by an arm bolted to the end of the flask, were used to measure the amounts of contraction. A 16 mm. film moving picture camera, operated by a synchronous motor, recorded the amount of shrinkage and the temperature every 15 seconds. The temperature was recorded by a pyromillivoltmeter with a temperature range of 0°-1600° C. (320°-2912° F.). The contraction was measured by Ames dials graduated to read to 0.001 in. The true free contraction of the bar was obtained with both ends of the bar free and two Ames dials to record the contraction.

16. The runner box, which was used for convenience during pouring, was slotted at the base so that the excess metal would run out and not act as a feeding head or restrict contraction.

Type of Steel

17. The steels were made in a 500 lb. per hr., Swindell, 3-phase, electric-arc furnace. The basic double-slag practice was used entirely during the collecting of the data presented in this report. In all cases, the steel-making conditions were duplicated as nearly as possible so that the data obtained could be carefully checked.

Pouring

18. The steel was poured from a teapot ladle so that the slag had very little opportunity to enter the mold. The pouring temperature of the steel entering the mold was between 2880° F.

(1582° C.) and 2800° F. (1538° C.). Aluminum, in amounts equivalent to 500 grams per ton, was added to the ladle prior to pouring.

Recording and Duplicating of Data

19. After the bars had cooled to room temperature, the films, giving a photographic record of the temperature and shrinkage, were developed, projected, and the readings recorded. Each time the contraction studies were made, the data were taken in duplicate. This required a set of eight molds to duplicate the four types of contraction. The results obtained were in excellent agreement; in fact, the discrepancies recorded were less than the average error indicated in the previous publication. When the differences in the results obtained with any alloy composition did not fall within the limits of error that had been arbitrarily set, the experiment was repeated and new data were obtained.

20. Shortly after the data were presented on the free and hindered contraction of carbon steels, a steel foundry executive pointed out that the data were collected, quite correctly, from steel poured within a relatively narrow temperature range. Since pouring temperature can vary considerably, it was deemed advisable to study the free and hindered contraction of the same heat of steel poured at high and low temperatures. One set of bars was, therefore, cast at approximately 1605° C. (2925° F.) and another set at approximately 1440° C. (2625° F.), a difference of 165° C. (300° F.) in pouring temperature. The plotted data were very close together, within the limits of error of the test, and the final end-points were practically identical. This points out, as was expected, that the differences in pouring temperature had no effect on the duplication of the data or on the final results.

DATA OBTAINED

Types of Alloy Steels

21. Studies were made of the free and the hindered contraction of the alloy steels listed in Table 1. A glance at the table will be sufficient to observe that only a small number of the many commercial alloy combinations have been studied. However, most of the single alloy steels and several important dual combinations are reported.

Table 1

Analyses of the Alloy Cast Steels

Steel No.	Type	Percent C	Mn	Si	Ni	Cr	Cu	Mo	Va
1	Carbon	0.35	0.74	0.37	....	....	....	....	....
2	Manganese	0.32	1.32	0.41	....	....	....	....	....
3	Nickel	0.34	0.64	0.41	3.00	....	....	....	....
4	Chromium	0.35	0.75	0.35	....	1.03	....	....	....
5	Copper	0.36	0.72	0.35	....	....	1.39	....	....
6	Molybdenum	0.37	0.77	0.35	....	....	....	0.39	....
7	Vanadium	0.32	0.65	0.37	....	....	....	....	0.25
8	Manganese-Silicon	0.36	1.35	1.15	....	....	....	....	....
9	Nickel-Manganese	0.32	1.24	0.30	1.46	....	....	....	....
10	Manganese-Molybdenum	0.35	1.18	0.30	....	....	....	0.37	....
11	Manganese-Vanadium	0.37	1.41	0.30	....	....	....	....	0.16
12	Nickel-Chromium	0.37	0.73	0.34	2.88	0.91	....	....	....

Table 2

Data on Freely Contracting Alloy Cast Steel Bars

Steel No.	Type of Steel	Percent Contraction Before Critical Range	Percent Expansion Passing Through Critical Range	Percent Contraction After Critical Range	Percent Total Contraction
1	Carbon	1.47	0.10	1.03	2.40
2	Manganese	1.74	0.26	0.88	2.38
3	Nickel	1.72	0.20	0.87	2.40
4	Chromium	1.46	0.14	1.02	2.34
5	Copper	1.49	0.14	1.00	2.35
6	Molybdenum	1.65	0.04	0.72	2.33
7	Vanadium	1.40	0.09	1.02	2.32
8	Manganese-Silicon	1.54	0.14	0.96	2.35
9	Nickel-Manganese	1.70	0.19	0.86	2.37
10	Manganese-Molybdenum	1.68	0.02	0.66	2.32
11	Manganese-Vanadium	1.50	0.13	0.96	2.33
12	Nickel-Chromium	1.95	0.04	0.36	2.27

Freely Contracting Bars.

22. The data obtained from the freely contracting bars are given in Table 2 and are shown graphically in Figs. 1, 3, 5 and 7. The data, unfortunately, fall so close together that it was found impossible to show all of the curves in one chart. It was, therefore, necessary to classify them by chemical composition and to

show them in four charts. The data for each type of contraction, however, will be considered as a unit.

23. Perhaps the most outstanding feature exhibited by the data is the fact that the plain 0.35 per cent carbon steel contracts more than the alloy steels studied. It is true, however, that the

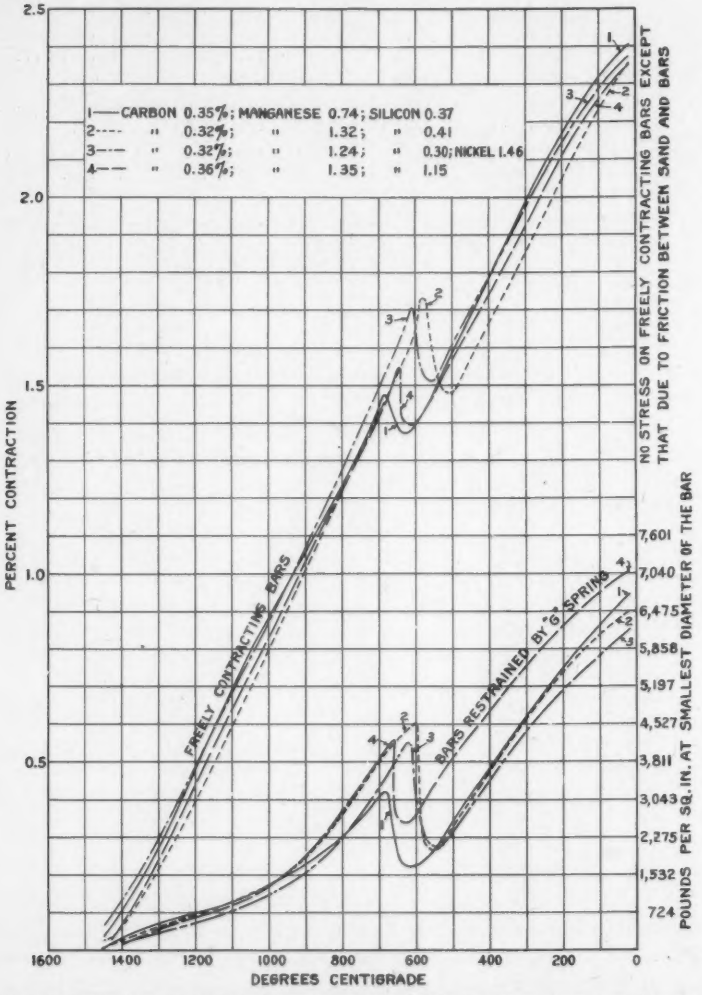

FIG. 1—CONTRACTION OF PLAIN CARBON AND ALLOY STEELS WHEN CAST INTO FREELY CONTRACTING BARS AND WHEN BARS ARE HINDERED BY "G" SPRINGS.

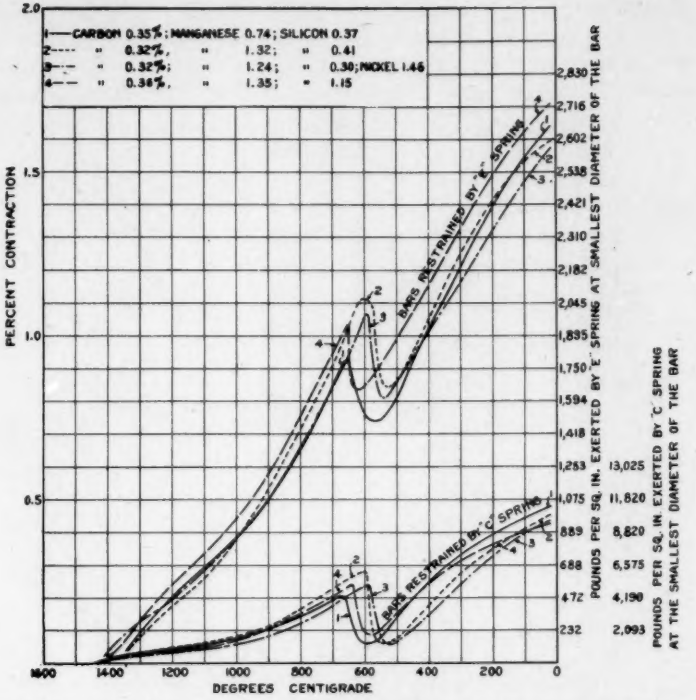

Fig. 2—Same Steels as in Fig. 1 When Cast Into Bars Hindered by "C" and "E" Springs.

differences between the total contraction of the various alloys are small. A further study of Table 2 reveals that, between the solidifying temperature and the critical range, the nickel-chromium steel contracted the most and the vanadium steel the least, while between the critical range and room temperature, the vanadium, chromium, and carbon steels contracted the most and the nickel-chromium steel the least. The amount of expansion occuring during the critical range was extremely low in the case of the molybdenum alloys, while the manganese steel expanded the most. In general, the contraction curves of the various alloys are practically parallel over any one temperature range, with the nickel-manganese and the carbon steel having the fastest contraction and the molybdenum and nickel-chromium alloy the slowest. The maximum variation, except through the critical ranges, is only about 0.08 per cent at any one temperature.

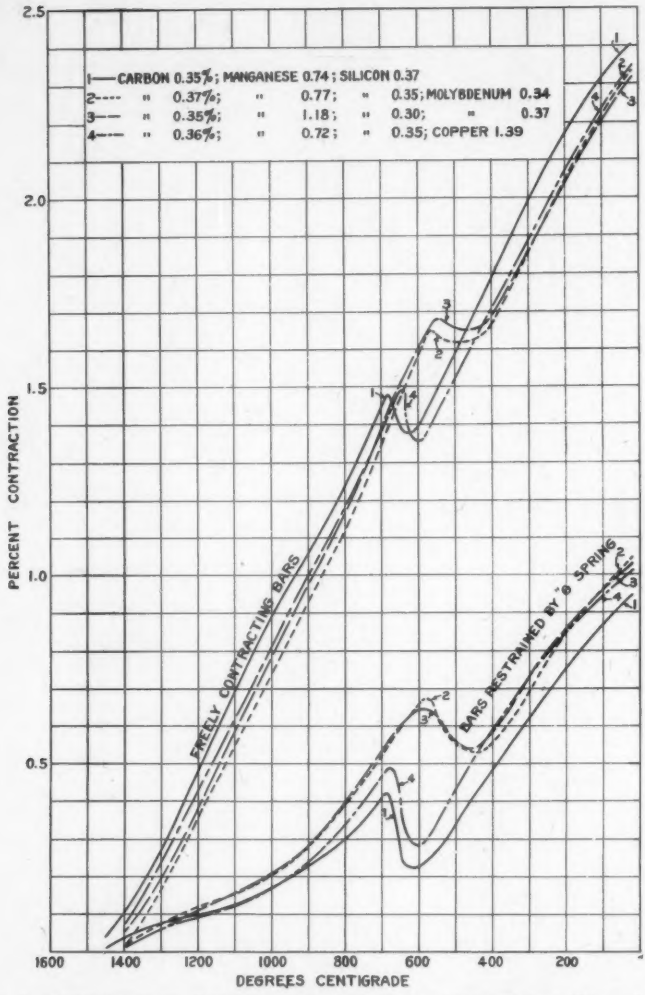

FIG. 3—CONTRACTION OF BARS OF PLAIN CARBON AND ALLOY STEELS WHEN CAST INTO FREELY CONTRACTING BARS AND BARS HINDERED BY "G" SPRINGS.

24. In Table 6, the critical temperatures of the freely contracting alloy steels are tabulated. All of the alloy steels studied, except the vanadium steel, have critical temperatures lower than that of the carbon steel. In general, it may be said that the lower the critical temperatures, the greater is the amount of contraction prior to the critical. A very interesting fact to be noted is the very

slight expansion of the molybdenum alloy steels while passing through the critical range.

25. The maximum variation between the curves after the critical range is of the same order as that which exists prior to the critical range; that is, if the nickel-chromium alloy steel is disregarded. The nickel-manganese steel alternates with the carbon steel in the upper position until a low temperature is reached when, due to a decrease in the rate of contraction, it drops to the third position. The nickel steel contracts practically the same amount as the carbon steel. The nickel-chromium steel has the least amount of contraction; this is probably due to the low temperatures of its critical range.

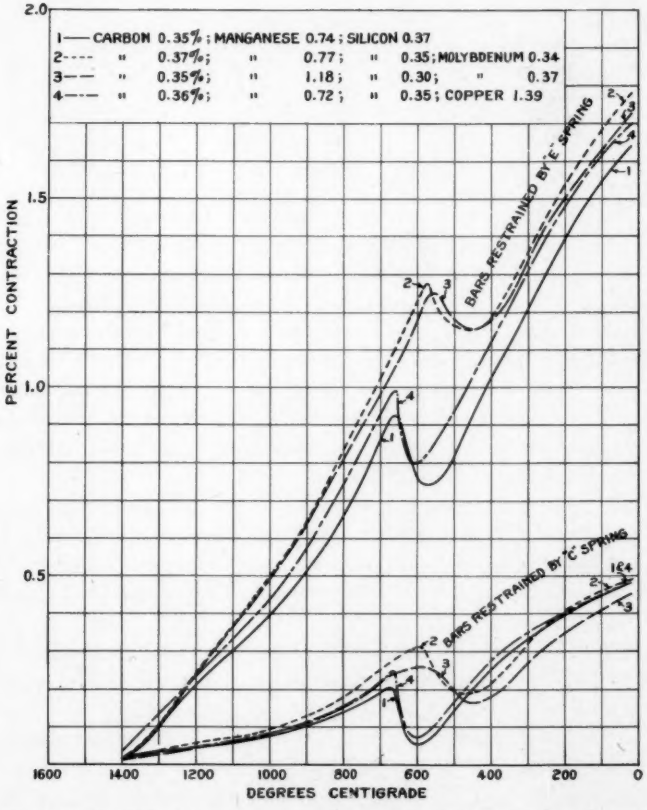

Fig. 4—Same Steels As in Fig. 3. Bars Hindered by "C" and "E" Springs.

Table 3

DATA ON ALLOY CAST STEEL BARS RESTRAINED BY LIGHT "E" SPRING

Steel No.	Type of Steel	Percent Contraction Before Critical Range	Percent Expansion Passing Through Critical Range	Percent Contraction After Critical Range	Percent Total Contraction
1	Carbon	0.92	0.18	0.90	1.64
2	Manganese	1.12	0.27	0.73	1.58
3	Nickel	1.13	0.25	0.75	1.64
4	Chromium	0.93	0.24	0.97	1.65
5	Copper	0.99	0.19	0.90	1.70
6	Molybdenum	1.28	0.10	0.61	1.78
7	Vanadium	0.90	0.15	0.93	1.67
8	Manganese-Silicon	1.03	0.20	0.88	1.72
9	Nickel-Manganese	1.06	0.26	0.76	1.58
10	Manganese-Molybdenum	1.25	0.09	0.57	1.72
11	Manganese-Vanadium	1.08	0.22	0.85	1.72
12	Nickel-Chromium	1.48	0.14	0.26	1.60

Light Hindered Contraction ("E" Spring).

26. It has previously been explained that, in the study of hindered contraction, the bars were restrained from contracting by springs of three different sizes. These springs were used to cause tensions in the bars similar to those encountered by castings. The conditions presented by these springs may not be comparable in magnitude to the stresses actually encountered in commercial castings, but they do give an indication as to the effects due to restricted contraction. The values in lb. per sq. in. shown on the curves were computed for the smallest diameter of the bar which has a cross-sectional area of 2 sq. in.

27. The data obtained with the light "*E*" spring probably represent more closely the stresses encountered by the average commercial casting for the total contraction recorded under this tension approximates the "patternmaker's shrinkage" of $\frac{3}{16}$ in. per ft. (1.56 per cent).

28. The hindered contraction data obtained from bars restrained by the light "*E*" spring are given in Table 3 and shown graphically in Figs. 2, 4, 6 and 8. It may be noted in Table 3 that the carbon steel reference curve now exhibits a low total contraction of 1.64 per cent as compared to most of the alloy steels which range from 1.58 to 1.78 per cent with the molybdenum steel exhibiting the most contraction and the nickel-manganese and the man-

ganese the least. The table also indicates that the nickel-chromium steel had the largest amount of contraction prior to the critical range, while the vanadium alloy contracted the least. After passing through the critical range, the nickel-chromium steel contracted very little, due undoubtedly to its low critical temperature. The molybdenum and manganese-molybdenum steels exhibited very lit-

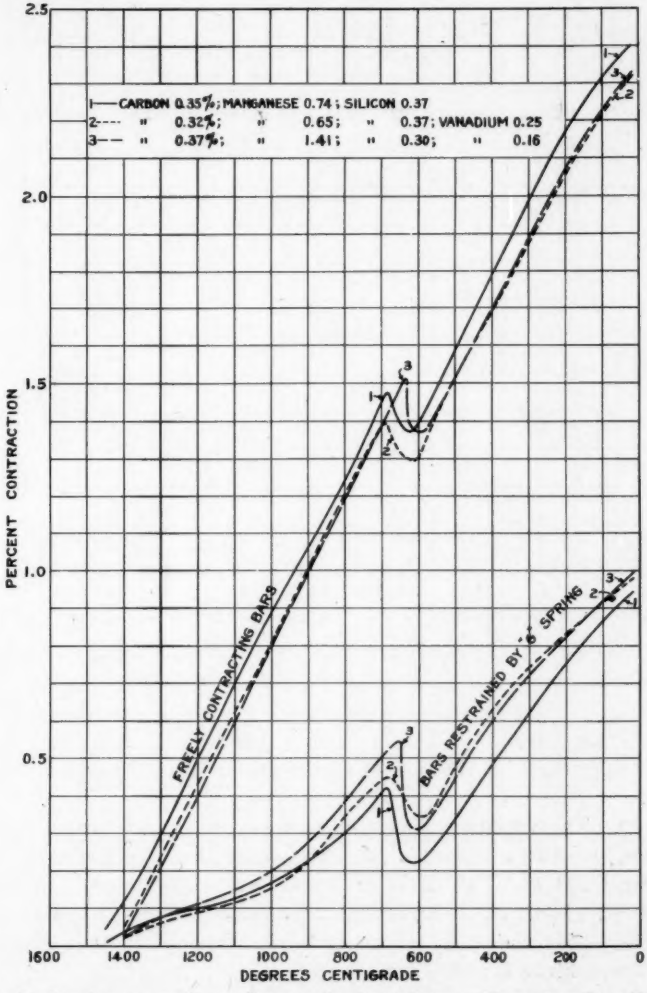

Fig. 5—Contraction of Plain Carbon and Alloy Steels When Cast Into Bars Freely Contracting and Bars Hindered by "G" Spring.

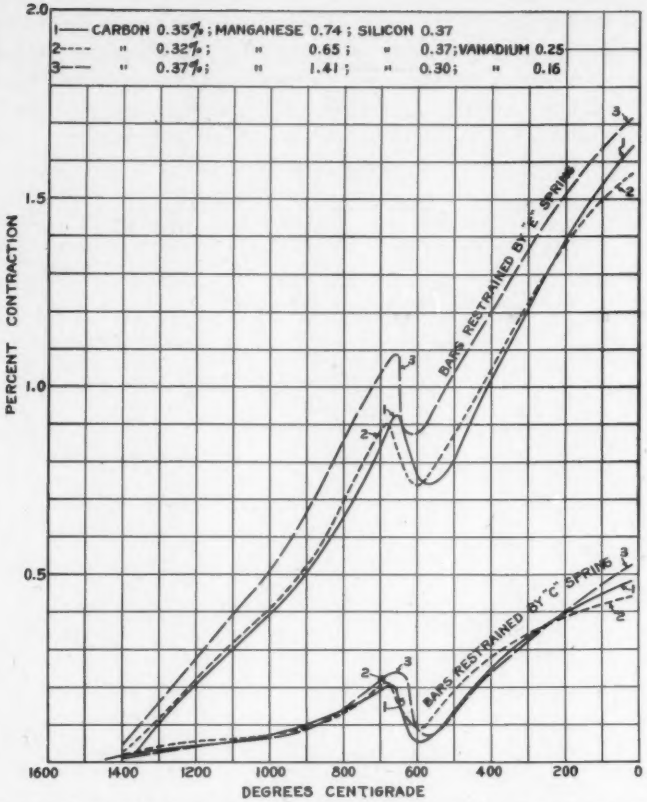

FIG. 6—SAME STEELS AS IN FIG. 5. BARS HINDERED BY "C" AND "E" SPRINGS.

tle expansion during the critical range, though it was considerably more than that obtained when the bars were contracting freely.

29. An examination of the curves will show that there is a decided bend at about 950° C. (1740° F.) indicating that a marked change appeared in the rate of contraction at about this temperature.

30. The variation between the upper and lower contraction curves indicates a difference in stress equivalent to about 250 lb. per sq. in. at 1300° C. (2372° F.) and about 350 lb. per sq. in. at 1000° C. (1832° F.). Thus, while the band of curves appears to be fairly wide, the actual difference in the stress on the bars at any one temperature is rather low.

31. The manganese-vanadium steel is the fastest contracting

steel prior to the critical, but it is followed closely by the molybdenum and manganese-molybdenum steels. The slowest contraction alternates between the manganese, the nickel-manganese and the carbon steels.

32. The critical temperatures for the bars restrained by the light "*E*" spring are given in Table 6. In general, about one-half

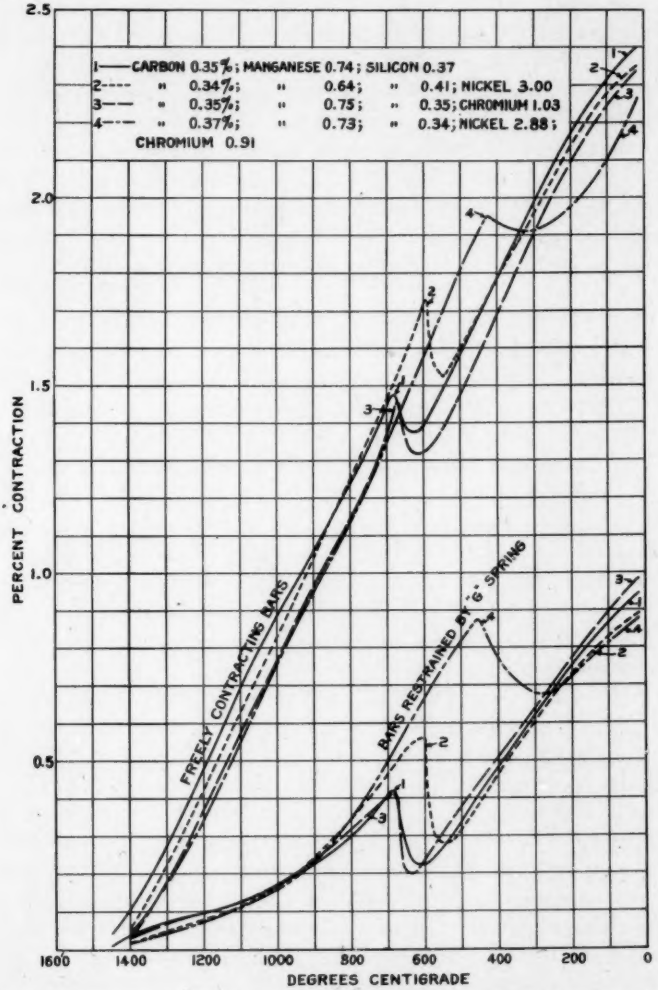

Fig. 7—Contraction of Plain Carbon and Alloy Steels When Cast Into Bars Freely Contracting and When Restrained by "G" Spring.

of the steels have critical points that are slightly lower in temperature than those recorded when the bar was contracting freely. The critical range of the nickel-chromium steel again exhibits the lowest temperature, while the highest critical temperature is recorded by the vanadium steel.

33. The differences between the curves showing the greatest and the least contraction after the steels have passed through the critical range are about 1.5 times those found above the critical range. The nickel-manganese steel is in the lowest position and the manganese-vanadium and the molybdenum steels show the greatest amount of contraction.

34. The rate of contraction of the manganese-vanadium steel falls off rapidly within the 200° C. (392° F.) to room temperature zone. This is a rather peculiar effect, although it is not exceptional, as approximately the same condition is found to exist with the nickel, manganese, and nickel-chromium alloy steels.

Medium Hindered Contraction ("G" Spring)

35. The data recorded with the medium "G" spring probably approximate conditions existing in castings which, due to design or to unusually high mold resistance, are unable to contract appreciably.

36. The data pertaining to the bars hindered by the medium *"G"* spring are set forth in Table 4. The contraction curves are to be found in Figs. 1, 3, 5 and 7. The total contraction varies from 0.88 per cent for the nickel-chromium steel to 1.05 per cent in the case of the molybdenum steel. This contraction corresponds to a stress of from 6150 to 7350 lb. per sq. in., respectively. The 0.92 per cent contraction of the carbon steel is very nearly the lowest amount of contraction recorded.

37. The different critical temperatures, as shown on Table 6, are again generally responsible for the different amounts of contraction before and after the critical range. The chromium steel has the least contraction before, and the most after the critical range, whereas the nickel-chromium steel, because of its low critical temperature, has most of its contraction prior to the critical range. The greatest expansion during the critical range is that recorded by the manganese steel, while the molybdenum alloys again show only a small amount of expansion. The carbon and the vanadium steels have the highest critical temperatures and the nickel-chromium steel has the lowest.

38. The variations between the upper and lower contraction

curves result in differences in stress varying from 300 lb. per sq. in. at 1300° C. (2370° F.) to 500 lb. per sq. in. at 1000° C. (1830° F.).

39. At temperatures above 1300° C. (2370° F.), the curves representing the contraction of the various steels cross each other and change positions so frequently that little can be said definitely about them except that the rates of contraction of the various alloy steels differ considerably. In general, it can be said that at any one temperature the nickel-manganese steel contracts the least prior to the critical range, while the manganese-molybdenum and the molybdenum steels contract the most. This condition is likewise true at temperatures below the critical range.

40. The variations between the curves at temperature below the critical are over twice as great as those before the critical range is reached. The three nickel alloys exhibited the least amount of total hindered contraction.

Heavy Hindered Contraction ("C" Spring)

41. The tensions exerted by the strong *"C"* spring are probably greater than any encountered in commercial practice, but the data indicate how these unusually high stresses would affect contraction. The data obtained by hindering the contraction of the bar with the heavy *"C"* spring are tabulated in Tables 5 and 6 and illustrated in Figs. 2, 4, 6 and 8.

Table 4

Data on Alloy Cast Steel Bars Restrained by Medium "G" Spring

Steel No.	Type of Steel	Percent Contraction Before Critical Range	Percent Expansion Passing Through Critical Range	Percent Contraction After Critical Range	Percent Total Contraction
1	Carbon	0.46	0.24	0.71	0.92
2	Manganese	0.60	0.33	0.64	0.90
3	Nickel	0.56	0.28	0.61	0.89
4	Chromium	0.41	0.21	0.78	0.99
5	Copper	0.49	0.21	0.73	1.01
6	Molybdenum	0.67	0.14	0.52	1.05
7	Vanadium	0.45	0.11	0.64	0.98
8	Manganese-Silicon	0.56	0.22	0.70	1.01
9	Nickel-Manganese	0.55	0.28	0.58	0.86
10	Manganese-Molybdenum	0.64	0.10	0.50	1.03
11	Manganese-Vanadium	0.55	0.24	0.69	1.00
12	Nickel-Chromium	0.87	0.20	0.21	0.88

42. The total contraction varies from 0.37 per cent for the nickel-chromium steel to 0.53 per cent attained by the manganese-vanadium steel, the carbon steel contracting 0.47 per cent.

43. In general, the critical temperatures are slightly above those found in the freely contracting bar. The general condition that the lower the temperature at which the critical range occurs, the greater will be the amount of contraction prior to the critical range, again exists. Thus, the nickel-chromium steel again leads by attaining 0.37 per cent contraction before the critical range is reached. The carbon steel shows the smallest percentage of contraction.

44. The chromium and carbon steels have the greatest amount of contraction after the critical range, whereas the nickel-chromium

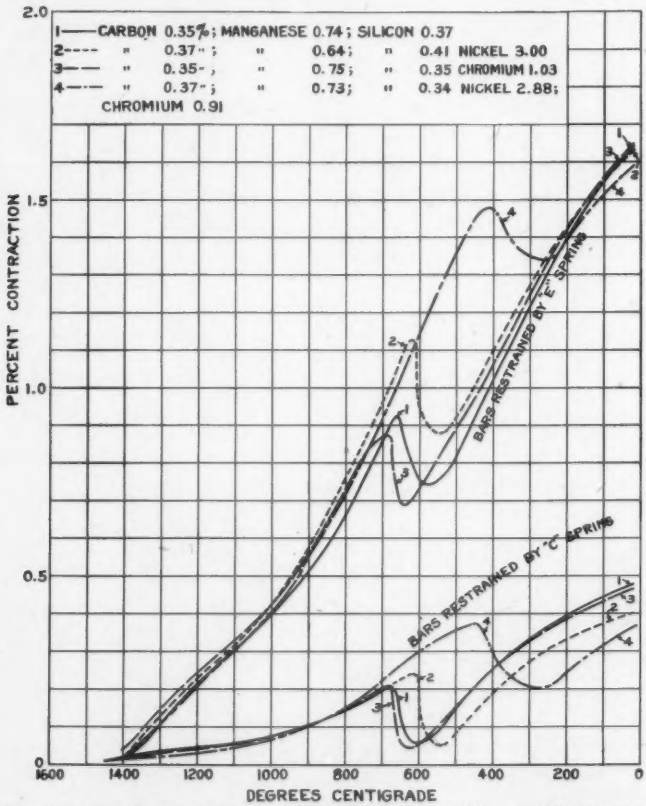

FIG. 8—SAME STEELS AS IN FIG. 7 BUT HINDERED BY "C" AND "E" SPRINGS.

Table 5

Data on Alloy Cast Steel Bars Restrained by Strong "C" Spring

Steel No.	Type of Steel	Percent Contraction Before Critical Range	Percent Expansion Passing Through Critical Range	Percent Contraction After Critical Range	Percent Total Contraction
1	Carbon	0.20	0.15	0.42	0.47
2	Manganese	0.28	0.22	0.39	0.46
3	Nickel	0.24	0.18	0.35	0.40
4	Chromium	0.21	0.17	0.43	0.47
5	Copper	0.25	0.17	0.41	0.48
6	Molybdenum	0.31	0.12	0.30	0.49
7	Vanadium	0.21	0.12	0.35	0.44
8	Manganese-Silicon	0.24	0.16	0.35	0.43
9	Nickel-Manganese	0.23	0.18	0.38	0.44
10	Manganese-Molybdenum	0.26	0.09	0.28	0.45
11	Manganese-Vanadium	0.24	0.16	0.45	0.53
12	Nickel-Chromium	0.37	0.17	0.17	0.37

steel contracts very little, in fact, only an amount equal to the expansion that took place when the steel passed through the critical range.

45. The manganese steel exhibited considerable expansion during the critical range and, under this heavy spring, the molybdenum alloys again expanded the least.

46. The variation between the high molybdenum curve and the nickel-manganese curve from 1400° C. (2550° F.) to 1000° C. (1830° F.) is only 0.03 per cent. This is equivalent to a difference in stress of about 650 lb. per sq. in. The curves representing the different alloys cross each other to such an extent that it is nearly impossible to point to any one alloy and to make predictions as to its ability to resist high contraction stresses.

47. The rate at which contraction takes place changes distinctly in two places. The curves flatten out between 1350° C. (2460° F.) and 1200° C. (2190° F.) and then, around 1000° C. (1830° F.) to 950° C. (1742° F.), there is a decided upward bend in the curves. At the lower temperatures, certain alloys show an appreciable drop in the rate of contraction, while other alloys have very little reduction in their rates of contraction. The decrease in the rate of contraction is most noticeable with the nickel-manganese and the manganese-vanadium steels. The rates for the

Table 6

CRITICAL POINTS OF ALLOY CAST STEELS ON COOLING FROM SOLIDIFYING TEMPERATURES WITH VARIOUS HINDERED CONTRACTIONS

Steel No.	Type of Steel	Critical Points — Higher								Critical Points — Lower							
		Free		Spring E		Spring G		Spring C		Free		Spring E		Spring G		Spring C	
		°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.
1	Vanadium	690	1274	685	1265	685	1265	690	1274	620	1148	600	1112	595	1103	595	1103
2	Carbon	690	1274	660	1220	690	1274	675	1247	635	1175	570	1058	615	1139	595	1103
3	Chromium	670	1238	680	1256	680	1256	680	1256	615	1139	640	1184	645	1193	630	1166
4	Manganese-Silicon	650	1202	645	1193	655	1211	640	1184	620	1148	620	1148	630	1166	585	1085
5	Copper	645	1193	660	1220	685	1265	670	1238	605	1121	600	1112	600	1112	600	1112
6	Manganese-Vanadium	640	1184	660	1220	655	1211	650	1202	605	1121	605	1121	610	1130	565	1049
7	Nickel-Manganese	610	1130	595	1103	635	1175	600	1112	560	1040	550	1022	550	1022	525	977
8	Nickel	600	1112	620	1148	610	1130	615	1139	545	1013	550	1022	550	1022	540	1004
9	Manganese	580	1076	605	1121	605	1121	605	1121	510	950	525	977	555	1031	535	995
10	Molybdenum	565	1049	575	1067	580	1076	590	1094	530	986	450	842	445	833	470	878
11	Manganese-Molybdenum	550	1022	550	1022	590	1094	580	1076	470	878	440	824	460	860	450	842
12	Nickel-Chromium	430	806	415	761	460	860	440	824	320	608	270	518	280	536	280	536

nickel, the vanadium, and the manganese-silicon steels also fall off appreciably.

48. The low final position of the nickel-chromium steel is probably due to its low critical temperature. All of the other steels are closely grouped except the manganese-vanadium steel which has a high end point due to its constant rate of contraction.

49. The effect of resistance upon contraction is illustrated in Fig. 9. The data shown are representative curves and were calculated from the average contraction of the bars at temperature intervals of 50° C. (90° F.). It should be noted that, in the freely contracting bars, the rate of contraction increased uniformly from the solidifying temperature to about 1200° C. (2190° F.). From 1200° C. (2190° F.) to the critical temperature, the rate of contraction is practically constant.

50. The bars which were restrained in contraction by the heavy "*C*" spring had an entirely different rate of contraction. In this case, the bar apparently yielded at the higher temperatures. The strength of the steel apparently increased slowly with the drop in temperature, since the amount of yielding is decreasing slowly as the temperature drops until at approximately 1200° C. (2190° F.), the strength is sufficient to cause an increase in the rate of contraction. Again at 1000° C. (1830° F.) the rate of contraction increases markedly.

Discussion of the Practical Features Exhibited by the Data

51. The total amounts of free contraction of the common types of low alloy cast steels are about the same, or slightly less than that of a plain carbon steel of the corresponding carbon content. This point, however, is not of great practical importance, since steel castings are seldom, if ever, in such a form as to allow them to contract freely. Thus a more practical viewpoint would be obtained by considering the characteristics of hindered contraction. The light "*E*" spring produces stresses approximately the same as those encountered by the average commercial casting. Under these conditions, the amounts of total contraction for the alloy steels vary from 1.58 per cent (practically $\frac{3}{16}$ in. per ft.) to 1.78 per cent (nearly 7/32 in. per ft.). The carbon steel, which was used as a standard, contracts 1.64 per cent (nearly 13/64 in. per ft.), occupies a position that is intermediate to the alloy steels ($\pm$ 1/64 in. per ft.). It thus appears that for all practical purposes the carbon steel and the alloy steels studied are similar. This condition holds true only as long as the percentage total contrac-

tion is considered. The rates of contraction, the position of the critical points, and the expansion during the critical range may or may not be similar to the characteristics exhibited by a plain carbon steel.

52. The statements given above concerning the hindered contraction under the light "*E*" spring are also true when more drastic conditions of hindered contraction are applied, such as those presented by the "*G*" and "*C*" springs.

53. It has been pointed out that, at any one temperature, there is a variation in the amount of contraction of the alloy steels. Although the difference between the steels contracting the fastest and those contracting the slowest is not great, important stress differences are recorded under hindered contraction at higher temperatures. For example, under the heavy "C" spring at 1300° C. (2370° F.), the vanadium steel bar is under a stress of 900 lb. per sq. in. at its smallest section, while the nickel-manganese steel has only a stress of 420 lb. per sq. in. acting upon it. Thus, at these high temperatures under large amounts of hindered contraction, the vanadium steel is subject to over twice the amount of stress that is acting on the nickel-manganese steel. Furthermore, it is not until a temperature of 1100° C. (2010° F.) is reached that the nickel-chromium steel must withstand the same stress as that to which the vanadium steel is submitted at 1300° C. (2370° F.).

54. The condition stated above has no bearing on the ultimate strength of the steel, however, except that it shows that the slower contracting steel may have a lower yield strength at the higher temperatures. This was pointed out when it was explained that the bars in contracting could only develop a stress equal to their yield strength. When the yield strength was exceeded, the steel yielded, thus causing a relieving of the stress. Upon further contraction of the steel, the stress is again built up to the yield strength. Thus the vanadium steel apparently has, at 1300° C. 2370° F.), about twice the yield strength of a nickel-manganese steel. This is important from a practical standpoint for it gives an indication of the yield strengths of the alloy steels when contraction has been hindered at high temperatures.

55. It can be seen that the apparent yield strengths, and not the true yield strengths, of the steels are recorded as the stresses upon the bars at any one temperature vary considerably with the type of contraction. For example, the vanadium steel at 1300° C. (2370° F.) has contracted 0.064 per cent when restrained by the "*G*" spring and only 0.044 per cent when restrained by the heavier

"C" spring. The bars, therefore, are under a stress of 465 lb. per sq. in. when the "*G*" spring is used and under a stress of 920 lb. per sq. in. when the "*C*" spring is used. As the bars cannot maintain a stress greater than their yield strength, the values given above are the apparent yield strengths of the material under these two conditions. The only difference in the conditions when these two springs are used, is the rate at which the stress is applied. The true yield strength would be indicated only if the stresses were applied at such a rate that no contraction would take place. Under these conditions the stresses on the bars would be equivalent to the true yield strengths of the steels.

56. The apparent yield strength is recorded only under conditions of hindered contraction which produce rate of contraction-time curves similar to that shown in Fig. 9, and then only at those temperatures at which the curves have a negative slope, in other words, at those temperatures at which the rate of contraction is decreasing. A curve showing the average rate of contraction with the medium "*G*" spring has the same trend as that of the curve for the rate of contraction with the heavy "*C*" spring (Fig. 9). However, the contraction data recorded when the light "*E*" spring was used produced a curve of a different type which exhibited no decrease in the rate of contraction at the higher temperatures. Under these conditions, it appears that the apparent yield strength is not reached even at the higher temperatures and that only the plastic flow of the metal is recorded.

Summary

57. The data presented may be summarized as follows:

a. The free contraction of a plain 0.35 per cent carbon steel is greater than that of any of the alloy steels studied. The total percentage of free contraction varies from 2.27 per cent, attained by the nickel-chromium steel, to 2.40 per cent, recorded by the nickel steel.

b. The amount of contraction taking place in both freely contracting and hindered contracting bars prior to reaching the critical range is, in general, dependent upon the temperature at which the critical range occurs.

c. The total amount of hindered contraction obtained corresponds closely to that exhibited by the plain carbon steel. The relative final positions of the different alloys vary somewhat with different amounts of tension on the bars.

d. The amount of expansion shown by the alloys during

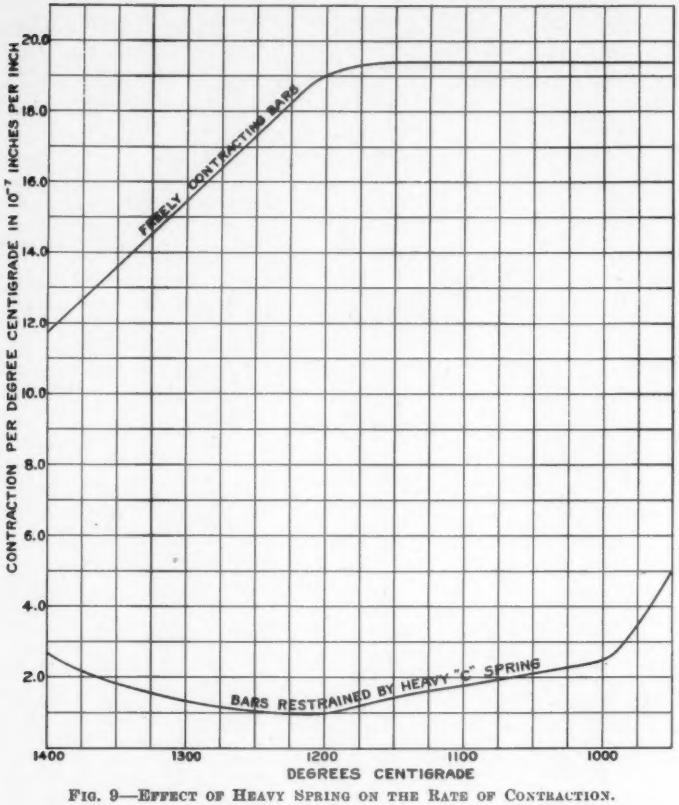

FIG. 9—EFFECT OF HEAVY SPRING ON THE RATE OF CONTRACTION.

the critical range varied considerably. In general, the amount of expansion under hindered contraction is greater than that recorded with freely contracting bars.

e. Differences in the pouring temperature of the steel have no effect upon the total amount of contraction in the solid state or upon the shape of the contraction curve.

ACKOWLEDGMENT

58. The authors wish to express their appreciation to various members of the Naval Research Laboratory for their ready co-operation in the research problem; Messrs. James Darby and Roy Donaldson for their aid in all phases of the test procedure, Tom Cunningham for his indispensable foundry abilities and Louis Singer for chemical analyses.

DISCUSSION

CHAIRMAN R. A. BULL[1]: I am sure I voice the sentiments of all present and many who are not present when I say the Association is greatly indebted to the authors for this, the fourth contribution of several very important ones that have been made in the investigation that has been carried on at the Naval Research Laboratory. Of course, the Navy is not taking an utterly unselfish attitude in carrying on this work. Naturally, having several steel foundries, the Navy wishes to improve its own practices and at the same time, it wants to help commercial steel foundrymen to improve theirs; all for the purpose of developing more satisfactory cast steel material for use on ships.

It must be obvious to everybody who has read this paper that it represents an immense amount of work of a scientific character that is related to practice. It needs to be studied and kept in one's file for such application to practical problems as one may be enabled to make from time to time.

F. A. MELMOTH[2]: Like all the rest of the papers by these authors, this one is of the type that has to be studied and one must try to find just where it ties in best with actual practice. They are all of great value if we can find the best method of using them and so making them mean something to us as actual producers. They are fundamental in character, and, like a lot of other such fundamental work, their purpose has been served, so far as the authors are concerned, when they have given us the facts.

I had thought of asking the authors whether any of their bars cracked, but Mr. Briggs anticipated this, because in his introduction he said that none of them did crack. But I wonder just why they did not crack; because, if we take a casting of any length and cast it with a gate on one end and a riser on the other, unless many precautions are taken, the casting most surely will crack.

In the case of the heavy loading spring used by the authors, it is conceivable that a greater resistance to contraction, and, therefore, a heavier strain exists, than is normal in a similar casting normally made in green sand. Yet these castings did not crack, in spite of their being gated just where one would never think of gating them, with the possible tendency of producing a hot spot right in the center.

Now it seems to me that if we did the same sort of thing with castings, cracks would result. Wherein, therefore, is the difference, and where is the practical significance?

In addition, Mr. Briggs tells me he has produced some bars which he has fastened solidly at both ends, and none of these cracked either. When he fastens them in this manner, solidly at both ends, then he has the maximum amount of strain due to contraction which can possibly occur, yet he assures me that no bars cracked.

We have a habit of saying that a casting cracks due to design and, no doubt, this often is true, but did any designer ever give us anything worse than a bar fastened tightly at both ends to be poured from steel?

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[1] Consultant on Steel Castings, Chicago, Ill.

[2] Vice President, Detroit Steel Castings Co., Detroit, Mich.

MR. GEZELIUS: It is possible to make the bars crack by altering the design. The bars used in this experiment cool practically uniformly throughout their length. If we use a bar that has the same cross-section except for the central 6 inches, and make the central section a little larger so that a hot spot is present, and tie that bar down, it will crack every time. But a straight bar, or a bar that is tapered so that it cools practically uniformly throughout its entire length, does not crack. In fact, we have elongated bars of this type with a small tensile machine and failed to break them. We are speaking of bars of the conventional sulphur content.

MEMBER: Was any rupture shown at all, or any hot tears? If you had an X-ray picture taken, would it show anything in the way of hot tears?

MR. GEZELIUS: They were perfectly solid.

C. E. SIMS[3]: I have great sympathy for Mr. Melmoth's attitude. I like to know why things happen and this work of Messrs. Briggs and Gezelius is obviously aimed at the cause for hot cracks and what means we can take to cure them.

My own work on hot cracks has convinced me: first of all, that it is a rather complex subject, and the only way we will ever make any material progress is by slowly, painstakingly gathering fundamental information which will enable us to interpret results that we get. From that standpoint, I think the authors' work is of the highest value. They are going at it in the correct way. It is not a fast way. It is going to be very slow. They have merely scratched the surface, as I think they realize.

I did some work on the problem of hot cracks in a somewhat different manner. My primary objective was to obtain a casting that would serve as a measuring stick to measure the tendency of a steel to form hot cracks. I made many tests, tried out numerous designs, practically everything I could think of, and to date I have to admit practical failure. Where I fell down was in my inability to duplicate results.

The first requisite of a yardstick is that it should be accurate, that it should give you the same measure two different times. I tried to get three castings poured consecutively from the same heat with molding conditions as nearly alike as I could make them and get castings that were alike in the matter of hot cracks. They varied tremendously. In two bars of a given design poured from the same heat, I might get cracks in one that would be ten times as bad as in the other.

Touching on what Mr. Melmoth referred to, I cast bars of uniform cross-section throughout their length, tied at the ends to a rigid steel insert in the mold. They were hooked over this steel insert in such a way that it did not act as a chill except on the ends of the bar, but it did completely restrict their contraction. The bars, when cold, were the same length as the pattern that was used and still there was complete absence of any sign of cracks. Examination of these bars consisted of breaking them and sometimes etching them to see if there were any evidences of cracks.

I went further. I produced bars that were larger in the center than

[3] Battelle Memorial Institute, Columbus, O.

at the ends, sort of cigar-shaped bars. These also failed to crack. But when I made a notch in the bar, I got a very pronounced crack and often complete fracture. If I put a projection on the side of the bar to form a "re-entrant angle", I got cracks in this angle.

To make a long story short, it appeared that the conditions necessary to produce a hot crack consist almost entirely of producing a hot spot on the casting, or a portion of the casting that will be greatly retarded in its cooling rate as compared with the rest of the casting.

That in simple terms, I think, is the explanation of hot cracks,—a pronounced non-uniformity in cooling. Those bars were 14 in. long over all.

When we speak of the cracks produced by hard cores, it seems a little paradoxical to think you can cast over a steel insert where there is complete rigidity and no chance for crushing the steel insert, to have complete absence of cracks.

JOHN HOWE HALL[4]: I am learning more than I thought I was going to from this discussion of hot cracks, but possibly I can contribute a little, too. I am going to ask Mr. Sims if my reasoning was all wrong in the way I attacked the problem he was working on?

I figured if I made a series of T-shaped bars of the same cross-section, each one a little longer than the other, casting them all in very hard cores, pouring them as nearly as possible under the same conditions, that the measure of the tendency of any given steel to hot crack was the length of bar above which all bars cracked. In my particular specialty, which is austenitic-manganese steel, I found that a series of bars like this will give reproducible results in most cases.

With that steel the factor that most affected hot cracks was metal temperature. If you poured a heat very hot, all the bars down to as low as say 4 in. would tear. If you poured the steel very cold, bars even up to ten in. long could be poured practically every time without tearing.

I did not start off in that investigation to measure the effect of pouring temperature; I started off to try to get some light on the long-standing question in the manganese steel industry, as to whether steel making processes have anything to do with the tendency to hot tear. The manganese steel industry happens to be one in which the fixed belief obtains that converter and open-hearth steels are not as likely to hot tear as electric steel, especially if the electric steel is made with a large proportion of remelted scrap.

When I tried to get some light on the same problem that Mr. Melmoth and Mr. Sims were speaking of, the tendency of intermediate manganese steel, for instance, to hot check as compared to carbon steel, I was stymied exactly the same as they. With the hardest cores I could make we poured bars up to two feet and even three feet long without getting tears.

Our tests did not throw much light on the subject, although at that time, in a few complicated castings we were making, we were having constant trouble with hot tears. I think, as Mr. Sims and Mr. Melmoth say, re-entrant angles and heavy sections producing hot spots have a lot to do with the formation of hot tears.

[4] Taylor-Wharton Iron and Steel Co., High Bridge, N. J.

R. E. APTEKAR[5]: There is a thought, I believe (disregarding the limitations of the discussion to the metal alone) that has a very practical application to the results of the paper we have just heard. And that subject is sand. A very practical aspect in application of the knowledge that we have gained in this paper today would be to consider a mold and a casting as being two equally important parts of the produced part. If we may disregard for a minute the inherent tendency of one type of steel or another type of steel to develop cracks, I should like to bring up the subject of sand resilience.

I believe that we have reached the stage in our knowledge of sand and sand behavior where we should look forward to being able to develop similar critical curves showing the behavior of sand throughout the various ranges of contraction. I believe if we could give a name to that property, that property would be the resilience of our mold. We want a strong mold to get the proper handling of our flasks, proper uniformity and conformity to our pattern. On the other hand, all steel foundrymen are quite familiar with the fact that a hard core will result in cracks regardless of the theoretical consideration causing it.

It seems to me our next step in the study of this problem must be, as I pointed out, a study of the critical behavior of the correlation between temperature and the yield of the sand itself. I do not wish to anticipate our committee report, but to that end there has been some discussion in the Molding Sand Research Committee in which we are very hopeful in the course of the next year or two of being able to develop sufficient data on that point that will give us a true picture as to what type of materials we must use to give us the high green strength that we require and to give us the proper relationship between yield in the sand itself and the casting.

GEORGE BATTY[6]: I maintain this question of cracking is tied in with design practically every time. Mr. Sims produces evidence that the so-called re-entrant angle gives cracks, because it is a hot spot. On account of the design, we have the inability of the mold to uniformly absorb or take off temperature from the steel, and while we have heterogeneous design, we are going to have troubles with cracking, hot cracking particularly.

In its practical application, it simply means we are driven further and further to outside means to control the rate at which the mold takes the temperature from the metal throughout the whole of the casting in relation to the temperature gradients being produced in both mold and metal in the act of pouring. It is still a foundry problem, related to design.

MR. SIMS: I did not want to be misunderstood in any statements I made with regard to the matter of curing hot cracks. There are many ways in which the problem can be tackled. I have seen hot cracks quite effectively cured by mold relieving. In view of what I said before, in spite of the hot spot in the casting, if there were no stress, still there would be no hot cracks. There are types of hot cracks which no amount

[5] Assistant General Superintendent, Foundries, American Brake Shoe and Foundry Co., New York, N. Y.

[6] Consultant on Steel Castings, Drexel Hill, Pa.

of mold relieving can cure, such as those in corners. We have to analyze all those things and get right down to rock bottom on the causes, and there is no one means that is going to cure all cases.

MR. MELMOTH: I do not think there is a practical steel founder in this assembly that has not seen hot cracks that have no obvious connection with hot spots. If we are going to put down all cracks to design, we have to blame them to local inequalities of temperature. In our own plant, in the past week, we had the misfortune to have some castings which cracked where there appeared no possible chance of their being affected to localized hot spots. These castings cracked because the thickness of the casting at that particular point was not great enough to overcome the strength of the rammed sand around which the steel was poured. An eighth of an inch additional thickness entirely stopped the trouble.

Therefore, there must be a reason for such a casting cracking other than a hot spot. The reason in this case was because it was subjected to too much strain. Nothing we tried would cure these cracks, but when the additional ⅛-in. metal was added the trouble was over. I would add that the metal was perfectly even at the point of fracture.

Now to return to the authors' example; Mr. Batty makes the point that the sand in the locality gets very hot during pouring, due to its inability to conduct away heat, thus producing a hot spot, maybe even on a uniform section. Do you not think that this is true in the case of these experimental bars? All the metal which goes into each casting has to pass through the gate into the mold cavity. The sand itself must be hotter in the vicinity of that gate than further out. The rate of heat extraction at that point is therefore slower. If the rate of heat extraction is slower, a hot spot must be produced, or I have an altogether incorrect conception of what a hot spot really is.

MR. HALL: If you want to see hot tears, you want to deal with Hadfield's manganese steel, and if you want to see a foundry that has to release a lot of molds, go into a manganese steel foundry. Some of those manganese steel test bars that I spoke of, 10-in. long, poured hot, were not satisfied to tear in one place, they tore in three. The fact that they tore in three places is interesting; if a straight bar tears in several places in contracting, there is something more to make it tear than the resistance of the core to the contraction of the bar, and that cause is sand grip. We once poured some pins of manganese steel, about 2½-in. in diameter, four in a flask, and of absolutely uniform section from one end to the other. They were poured through a central runner and bottom gates, and the metal did not run over the top of the cope. But they were poured too hot, and all four tore completely in two in the middle, simply from sand grip. The presence or absence of sand grip has quite an effect on hot tearing. Mr. Ballard just suggested to me, and I believe he is right, that one of the reasons why we do not get more hot tearing than we thought we were going to in the new molding process we are all interested in of late, is the fact that those molds are freer from sand grip than sand molds are.

CHAIRMAN BULL: This illustrates the aptness of Mr. Aptekar's comments on the possible influence of sand and the potential value of his particular Committee's report in connection with this matter of hot cracks.

I think probably all of us have seen cracks that we diagnosed as resulting from extremely rough surface of the casting and this, in turn, caused by the condition of the sand. I know I have seen that. When the casting did not have the opportunity to crawl naturally, as it contracted in the mold. In that connection, I wonder whether the condition of the sand mold as to dryness or dampness might have something to do with some of these experiments. For instance, a specimen might be sufficiently small in size and cross section, when poured in green sand, to freeze very quickly, whereas the same specimen, if cast in a dry mold (possibly preheated before pouring) might show different results, simply from maintaining the fluid condition of the specimen for a longer period and giving it an opportunity to show what it might want to do if not cooled in an accelerated fashion.

P. E. MCKINNEY[7]: I do not think we should get to the point of viewing the purpose of the experiment to create a condition that will directly show up in the form of hot tears. As I have understood the experiments, the purpose was to get the characteristic of the cast steel under conditions as free from variables as possible to study the characteristics of solidifying steel. To me they are very interesting, and I see in the data that are presented a lot of food for thought, not only as to the amount of contraction under various degrees and various stresses that are set up by those springs, but by the dimensional changes that take place during contraction, and while passing through the critical range. That is something that we have done a good deal on in finished steel, by the dilatometer study of steel and dimensional changes taking place through the critical range. Some of us believe it has a great deal to do with the weldability of some steels as compared with others.

A further very interesting experiment on these same examples would be to determine the dimensional changes that take place on reheating and cooling, getting the condition of free contraction that takes place during the first cooling operation from a liquid to the solid, and the second cooling operation after reheating and going through a second cooling cycle.

Aside from this investigation, we will probably be making a study of some of these same examples. As I see it, the data we have here give us a lot to think about in the possible effect of those total dimensional changes, during the solidification of a complicated shape, that may in many cases give us some few reasons to expect a greater tendency of hot tearing in some cases than in others.

CHAIRMAN BULL: Have the authors any reason to think there may be a relationship between tendency to crack and initial grain size? This question is prompted by a comment in the paper on the experiment with steel containing vanadium. It is well known that one influence of vanadium is to produce a small grain size.

MR. BRIGGS: We have no information as yet on that point. High casting temperatures may alter the grain formation during solidification resulting in a larger grain structure, more pronounced Widmanstatten figures, etc., which in turn may effect the strength of the cast steel in the solid state. What the nature of this effect is, especially in regards to hot tear formation, I do not know.

[7] Metallurgical Engineer, Bethlehem Steel Co., Bethlehem, Pa.

We would like to thank Mr. McKinney for bringing out the point that this paper is not a study of hot tears. We have but very little to present on hot tears at this time. The paper was primarily a paper on the hindered and free contraction characteristics of alloy steels. We are very much interested in the hot tear problem and the strengths of steels at very high temperatures but our work has not progressed far enough along that line for us to discuss it. In this present study, we were primarily interested in obtaining a bar that would not crack. Our principal object was to present figures and data on the contraction of steel under various conditions of mold resistance. Some of these mold resistances are high and some low. Probably the ones that are high would cause commercial castings to crack, but it would have defeated our purpose entirely if we had developed a bar that would have cracked in any manner as then we could not have measured the stress that was on the bar at various temperatures.

CHAIRMAN BULL: If you had obtained one steel or perhaps two out of a dozen which would have cracked, while the others did not crack, then that would not have been so bad, would it, from your standpoint?

MR. BRIGGS: Certainly not as far as collecting hot tear in formation, Mr. Chairman. We are, however, developing at present a bar to study the hot tear condition. We have been on it for two years and a little over and it is quite an elaborate setup. What we are primarily doing is studying the physical properties, that is, the strength and elongation of steel at temperatures around 1300 or 1350° C. (2372 or 2462° F.), or in other words, soon after the steel has solidified. We are using a small type of tensile machine connected right to the mold. We have made several preliminary studies along this line and have found out quite a bit but nothing yet for publication.

CHAIRMAN BULL: It seems to me there are enormous possibilities of practical benefit in this kind of work, and I certainly hope it will continue to a very satisfactory conclusion.

MR. BATTY: I want to return to the subject of hot spots in steel castings and point out that although we are all well acquainted with the cracking of valves, pipes and fittings, such as Mr. Melmoth mentioned, and the very typical one opposite the root of a radius, there are other hot spots that we are apt to overlook.

Now, the Chairman and I have both had an opportunity lately of seeing some rather big castings, that is, they weigh between 5,000 and 6,000 lb. each, that have had hot tears of a type somewhat different from the one we are discussing this morning. These hot tears were associated with tiny inclusions, non-metallic inclusions, and they were not exactly an ordinary hot spot.

If we refer, also, to Woodward's paper* of two years ago we can read in it the consideration of certain defects and the significance attached to quite a small, local sand inclusion, or particularly to a string of them. Now, in the making of valves and fittings where the gating system is not adequate, where sand grains are washed from the gating system and lodged on the underside of the core, it very frequently occurs that a hot

* Woodward, R. C., *"The Mechanics of Porosity in Steel Castings,"* TRANS. A.F.A., vol. 42, pp.364-374 , (1934).

tear will occur along the lines of those inclusions, and we have to look for some very small aspects as well as some of the major aspects of both mold and metal in arriving at the absolute cause of some of these things. This creating of local hot spots, I think, is a bit under-rated at the present time, and we look a little more closely into it.

A. W. DEMMLER[8]: Since the question of vanadium has been raised, I would like to mention one thing in this connection. That is, in the several vanadium steels, the vanadium content is actually higher than commercial practice today.

Next, referring to the paper, I would like to know whether the authors have any idea as to why the critical on the nickel-chrome steel is so exceptionally low compared to all the rest of the series? Is that hysteresis in cooling from the freezing point, or is there something else?

MR. GEZELIUS: That is rather difficult to answer. Of course, in these tests we do not have conditions that are as nicely controlled as those in the laboratory when a dilatometer is used. We probably have a great deal more hysteresis than one would find in laboratory measurements.

As to vanadium content, before we selected the compositions of the alloy steels we sent out inquiries to at least a dozen men representative of the industry and asked them for suggestions. We received replies in which all of the alloy contents varied over a considerable range. What we did in each case was to take about the average, so that we were working under the assumption that the data we collected were obtained with a steel containing about the average amount of vanadium used in the industry. That may be erroneous but the amount used is the average obtained from the replies to a dozen, or more, inquiries.

[8] Metallurgical Engineer, Vanadium Corp. of America, New York, N. Y.

Recommended Practices for Sand Cast Magnesium Alloys*

Report of Nonferrous Division Committee on Recommended Practices

Preface

This is the second in a series of recommended practices being sponsored by the Nonferrous Division of the American Foundrymen's Association, the first being issued in 1934 (Trans. A.F.A., vol. 42, pp. 1-26). Others covering the various groups of alloys listed in the Cast Metals Handbook (A.F.A. 1935), Nonferrous Section, are in the process of review and will be published in the near future.

Although the various practices which are treated are recommended by those considered specialists in the various fields, these practices are not intended as specifications. The alloy numbers have no particular significance other than to differentiate alloys in this particular specification. Whenever possible, these numbers are identified with existing alloy specifications.

The publishing of data relative to various alloys and treatment of such alloys by the American Foundrymen's Association, does not insure anyone using such data against liability for infringement of any patents that may now exist or are pending. It should also be understood that the publication of data concerning patented alloys or processes does not constitute a recommendation of any patent or proprietory rights that are involved.

In preparing these recommendations, the Division has attempted to collect, through reliable sources, such information as will be of practical use to foundrymen handling nonferrous alloys.

This report is limited to magnesium alloys and is divided as follows:

A. General Recommendations

- *(1) Molding—(a) Sands, (b) Facings, (c) Gates and Risers, (d) Cores.*
- *(2) Melting and Pouring—(a) Melting, (b) Alloying, (c) Scrap Recovery, (d) Dipping and Pouring.*
- *(3) Finishing.*
- *(4) Heat Treatment*
- *(5) Defects, Their Causes and Prevention.*

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* Many phases of the magnesium foundry practice here described are covered by existing United States patents.

NOTE: This report was presented at a session on Non-Ferrous Castings at the 1936 Convention of A.F.A. in Detroit, Mich.

B. Properties and Applications.

(1) Chemical Control Limits.
(2) Physical Properties.
(3) Conforming Specifications.
(4) Development and Field of Use.

In preparing this report the Committee has been greatly indebted to Dr. J. A. Gann, Dow Chemical Co., Midland, Mich., for his preparation of the basic material.

Nonferrous Division Committee
on Recommended Practices

T. D. STAY, *Chairman*	H. B. GARDNER
W. M. BALL, JR.	H. W. MAACK
A. L. BOEGEHOLD	R. W. PARSONS
L. H. FAWCETT	H. J. ROWE
J. A. GANN	T. C. WATTS

A. GENERAL RECOMMENDATIONS

1. *Molding.*

(a) *Sands:* An open molding sand should be used to offset the lightness of the metal and allow steam and core gases to escape readily. Very satisfactory results are now being obtained from a synthetic sand with A.F.A. permeability of 50 to 60, prepared by adding 4 per cent of bentonite to a silica sand graded to 100 to 150 mesh. A small amount of a "sand addition agent" is mixed with the sand in order to inhibit oxidation of the hot magnesium by steam. The better sand addition agents include sulphur, boric acid, and certain ammonium salts, particularly the fluorides, used singly or as mixtures. The amount used depends upon the agent selected, the condition of the sand, and the thickness of the cast section.

A 75-25 water-glycol mixture is used as the tempering agent. In practice, the glycol is added to the sand and the tempering completed by the addition of the requisite amount of water. Thorough mulling is essential to insure uniform distribution of the bentonite, glycol, and sand addition agent and to improve the strength and plasticity of the sand.

The sand should not be hard-rammed close to the pattern; but as one proceeds away from the pattern, the ramming can be increased to insure safe handling of the mold without danger of drops. Light ramming improves the permeability of the sand and permits its contraction during the solidification and cooling of the castings. This contractability in both molds and cores is necessary to counteract hot-shortness in the alloys and so minimize the

danger of shrinkage cracks. The mold should likewise be freely vented to aid in the escape of gases.

(b) *Facings:* Special facings are seldom used in the magnesium foundry although with heavy castings or sand of relatively low permeability, it is sometimes advantageous to use a facing containing more of the addition agent, to dust the molds with finely powdered sulphur, or to surface dry the mold.

(c) *Gates and Risers:* Although gating practice varies necessarily from casting to casting, there are a number of fundamental principles that must be observed. The metal should, in general, enter the mold cavity at a low point (Fig. 1) with a minimum of splashing or turbulence, since mechanically entrapped

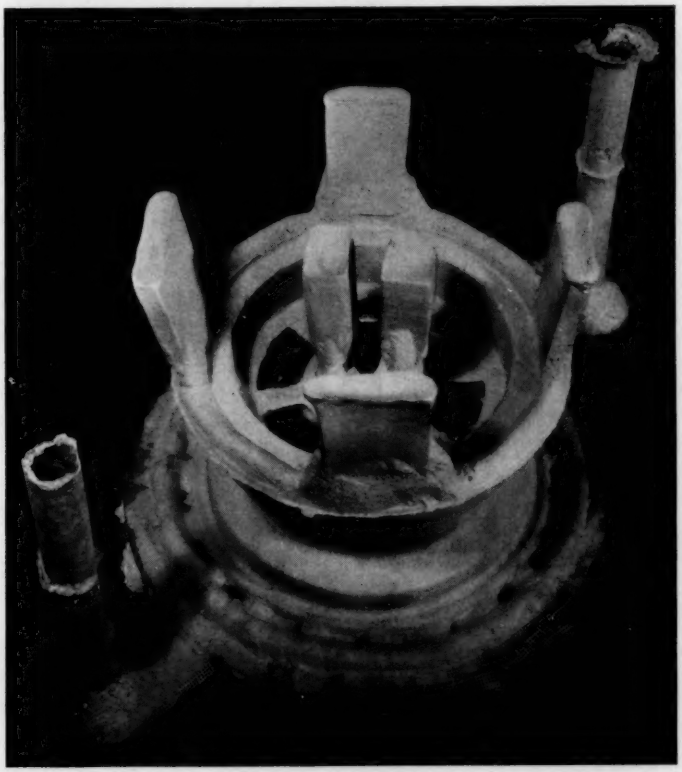

FIG. 1—CASTING WITH GATES AND RISERS ATTACHED.

gas forms oxide skins in the metal and these, in turn, increase the viscosity of the metal and retard any subsequent escape of gas. In some cases, however, it is advisable to introduce the metal at the center or top, providing the mold cavity has an incline to break the velocity and is without elevations and depressions that will create a turbulence before the metal reaches the bottom. This procedure often results in a more uniform solidification of the

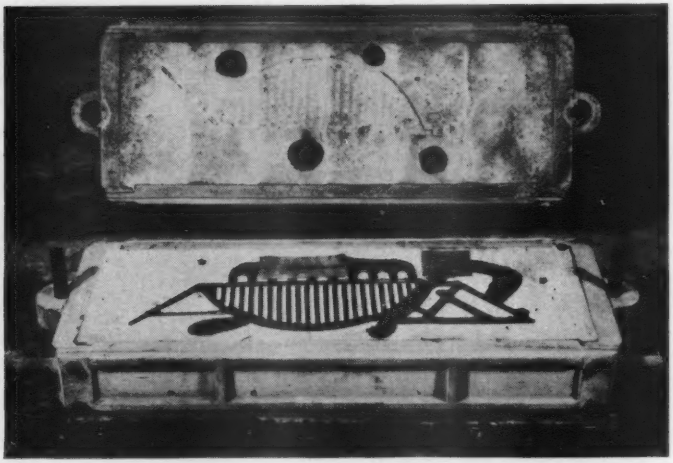

FIG. 2—OPEN MOLD FOR MAGNESIUM-ALLOY CASTING SHOWING GATING METHODS AND SKIMMERS IN THE GATE IN PLACE. TURBULENCE IS LARGELY OVERCOME BY PLACING SHEET-STEEL SKIM GATES AT BOTTOM OF SPRUE.

casting, thus helping to eliminate shrinks, cracks, porous sections, and in some cases misruns.

Turbulence, with its resulting evils, is largely overcome through the use of perforated sheet steel skim-gates (Fig. 2) containing eight to twelve perforations per inch. This screen is placed at the bottom of the sprue, and, in large complicated castings, a second screen is sometimes placed in the runner near the gates. These screens choke the flow of metal, thereby assuring a steady feed into the mold cavity, and also trap oxide skins that form on the surface of the metal during the pouring operation. Wedge gates that are wide and shallow and feed from the bottom of a hump or well, likewise aid in the removal of entrapped air and oxide skins but are less frequently used now that skim gates are so generally employed.

A number of finger gates are preferable to fewer large ones as they give a better distribution of heat in the casting and also prevent local overheating of the sand and generation of excess gas and water vapor. Similar objectives call for the location of gates on the thinner sections of the castings. Although the specific heat of the metal is high (0.33 avg. specific heat 70 to 1200° F.), the specific gravity of the metal is low, so that the total heat per unit volume is low. As a result, total gate area and runners should be of generous proportions to insure a free flow of metal. Risers should be large and connected as directly as possible to the section to be fed.

Progressive solidification of the metal should be obtained through the use of risers instead of chills wherever the riser will accomplish the same end, and provided it is located so that it does not introduce trouble in molding and trimming. When chills are used, they may be made from customary materials, such as iron and graphite, although best results are obtained from magnesium alloy chills. They must be clean and dry to avoid blows, and large ones should be perforated to aid in the escape of gas.

(d) *Cores:* Cores should be made from an open sand containing sulphur, boric acid, and an oil binder. They should be rammed no harder than necessary to insure retaining their shape before baking, and should be well vented. The oil binder should generate a minimum of gas and should permit the core to soften when contacted by molten metal. The cores are baked at 350 to 500° F. for 20 minutes to several hours, depending on the size of the core, after which they are given a graphite-alcohol wash and the alcohol ignited and burned off.

Green sand cores should be used wherever possible for smoothness and economy. They are made from the regular heap used for the production of molds.

2. *Melting and Pouring.*

(a) *Melting:* The "Dow Open Flux Pot Melting Practice" is one of the most widely used melting practices for magnesium and its alloys. It is based on the use of a large bath of a fluid flux (Fig. 3) that functions in a dual manner. This flux protects the molten metal from the air and furnace gases by completely enveloping it and, thereby, eliminates the dangers usually associated with prolonged holding of metal in the molten state and with overheating. It likewise purifies the metal by washing out non-

metallic impurities when the metal and flux are intimately mixed. The flux normally used consists of 60 per cent anhydrous magnesium chloride and 40 per cent sodium chloride, and has a specific gravity and surface tension that causes it to float the metal. The main body of flux lies in a pool at the bottom of the pot; but a thin film is formed between the metal and the walls of the pot, and across the top surface of the metal.

Melting pots are made of low carbon cast steel and are good for approximately 1000 hours of service. Pots holding 300 and 600

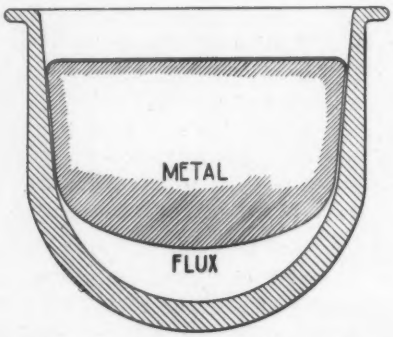

FIG. 3—THE MAIN BODY OF FLUX LIES IN A POOL AT THE BOTTOM OF THE POT BUT A THIN FILM IS FORMED BETWEEN THE METAL AND THE WALLS OF THE POT, AND ACROSS THE METAL SURFACE.

lb. of metal respectively are the sizes most generally used and are mounted in gas or oil-fired brick settings.

The charge for the smaller pot consists of 100 to 125 lb. of flux and 300 lb. of metal, added in the order named. The flux has a lower melting point than the metal and soon forms a bath to receive the metal as it melts down. The molten charge is now given a thorough puddling to bring metal and flux into intimate contact with each other, and thus insure complete removal of oxide and other nonmetallic impurities. Puddling is done with an open-bowl sludge ladle or with a casting ladle described later. The contents of the pot are then allowed to stand quietly for several minutes in order that the impurities may settle from the metal and flux, and form a sludge at the bottom of the pot. This sludge is removed at regular intervals, generally once a day unless very large amounts of scrap metal are melted.

More metal is added as required to replace that removed in

the production of castings. Each new charge is washed in flux as already described. The flux can be used repeatedly, but there should always be enough present so that it can be readily brought to the surface of the metal during the puddling operation, and so that the casting ladle can be cleaned in the bath of flux below the metal as explained later. Under normal conditions, one pound of flux is required for each 8 to 12 lb. of metal melted; this ratio depending on whether ingot or scrap is melted.

All material added to a pot of molten metal should be carefully preheated in order that absorbed moisture may be completely driven off. The foundry flux is very hygroscopic and, hence, should be stored in covered containers and should not be added to a pot containing molten metal. This hygroscopicity likewise calls for careful preheating of all equipment, such as ladles, thermocouples, iron molds, and sludge pans.

(b) *Alloying:* Substantially all magnesium castings are now made from the Mg-Al-Mn and Mg-Al-Mn-Zn groups of alloys. Aluminum and zinc alloy so readily that hardeners and special technique are not required. Manganese alloys more slowly and only to a limited extent. It is generally added in the form of a 90-10 aluminum-manganese hardener. The casting alloys normally contain 0.1 to 0.4 per cent manganese but since this represents approximately the solubility limit, more time and stirring are required than when alloying other metals. A 75 to 80 per cent alloying efficiency for manganese is considered good operating practice. Most of the excess of unalloyed manganese settles to the bottom of the pot, although a few particles of microscopic size remain suspended in the alloy. The alloying ingredients are placed in the ladle and then submerged and gently agitated in the molten magnesium, after which the entire charge is thoroughly stirred.

(c) *Scrap Recovery:* Massive scrap, such as sprues, gates and risers should be free from adhering sand and other contamination. They can be melted the same as ingot, except that the metal should be more thoroughly washed with flux. Metal skim-gates will cause no harm in the pot and can be dipped out with the sludge. In the case of poor quality scrap, it is good practice to use two pots on the counter-current principle, namely, to melt in the one containing the older and dirtier flux and after a preliminary wash to transfer the metal to the casting pot containing clean flux and wash again.

Machine shop scrap, such as shavings, borings, chippings, etc.

present a different problem because of the greater ease with which such finely divided metal can be ignited and because of the high ratio of surface oxide to metal. Obviously, this type of scrap should be kept dry and, preferably, free from oil or other cutting compounds. It is melted down at the lowest possible temperature, using plenty of flux and starting with a pot containing some metal in the pasty or semi-molten condition. A shovel full of shavings is then added and quickly stirred into the flux. The heat supply of the pot and the addition of shavings are so controlled that the metal in the pot remains semi-fluid. This low temperature operation practically eliminates any loss due to burning and gives maximum coalesence of the metal. When sufficient shavings have been added to fill the pot, the charge is gently stirred to complete coalesence and the temperature then raised to 1300 to 1350° F. for the regular puddling or washing operations. The pot contents are now allowed to stand quietly for a few minutes to allow the sludge to settle, whereupon, the metal is poured into ingots or transferred to the casting pot. If the melting and purification of scrap is conducted properly, the recovered magnesium alloy is equivalent to virgin metal. Contamination by foreign scrap must be carefully avoided, however, since it often contains copper or nickel, two metals that are very detrimental to magnesium from the standpoint of corrosion resistance.

(d) *Dipping and Pouring:* A ladle of special design (Fig. 4)

FIG. 4—TYPE OF CASTING LADLE USED FOR MAGNESIUM ALLOYS.

must be used to insure proper separation of the metal from flux and the delivery of clean metal to the mold. The essential features of such a ladle are the parting sweep, retaining shield, and underfeed pouring spout. The sweep is used to part the film of flux covering the surface of the metal in the pot and to permit the dipping of clean metal. Oxide films that form on the surface of the metal in the ladle are held back by the retaining shield. The entrance to the underfeed pouring spout is a short distance from the bottom of the pouring ladle and is provided with a flange thus retaining in the ladle any small amount of flux that may have been dipped with the metal.

Prior to pouring, the ladle is preheated and cleaned by washing in the flux underneath the metal at the bottom of the pot. After inverting and draining the ladle, it is rinsed two or three times with metal. This is accomplished by parting and skimming back the flux from a small area on the surface of the metal. The edge of the ladle is now held slightly below the surface, whereupon, clean metal flows into the ladle. Part of this metal is poured through the spout and the balance is poured rapidly out of the back of the ladle. The clean ladle is then filled with metal for casting as previously described in rinsing. If the flux film does not automatically reform as the ladle is lifted from the metal, the exposed surface is protected by sprinkling with powdered flux.

Surface oxidation of the metal in the ladle is minimized by dusting on a mixture of sulphur and ammonium fluoride salts. Any excess metal in the ladle, above that required for the casting, is poured back into the pot near its circumference. The ladle can be used repeatedly until fouled by adhering magnesium oxide, whereupon it is cleaned in flux.

When pouring a mold, the lip of the ladle is held quite close to the mouth of the sprue and the stream of metal is maintained as steady as possible to minimize turbulence and entrapping of gas. When the casting must be poured hot or when a large sprue is required, the surface of the metal in the sprue may start to burn. Such fires, or those caused by accidents such as runouts or spills on the foundry floor, are readily extinguished by covering with regular molding sand.

The lowest possible pouring temperature should always be used as this will insure sounder castings with maximum physical properties and will help reduce melting losses. Temperature control can occur in the pot or in the ladle, depending on whether

a single type of casting or a variety of castings requiring different temperatures are being poured. Iron-constantan thermocouples are very satisfactory. These are prepared by welding a constantan wire to the inside tip of a closed thin-walled iron tube. Open couples which expose the constantan to the molten metal should not be used.

3. *Finishing*

Castings are rough-trimmed to remove sprues, gates, and risers; sand blasted; and given a first inspection prior to heat treatment. Final clean-up generally follows the heat treating operations. Band saws, made from 20-gauge spring temper steel with 4 teeth per inch, are operated at a speed of approximately 4000 ft. per min. Power hack saws should have 10 teeth per in. and hand hack saws 14 teeth per in. Single-cut files are recommended and the type known as "body worker's" files are quite satisfactory for heavy work. Portable electric or pneumatic chippers, rotary files, and grinders are used to good advantage. Medium-hard grinding wheels (K to M for alundum) are recommended. A grain size of approximately 20 is satisfactory for foundry snagging operations, while a grain size of 30 to 46 is best for more accurate work.

Tools used on magnesium alloys should not be used for other metals to avoid the danger of sparks. This is particularly true with grinders due to the inflammability of the powder. Special precautions should, therefore, be taken to see that all skim gates and core wires are removed from the castings before grinding and that the wheels do not touch steel inserts. Operators' clothing should be of smooth cloth with no pockets or cuffs in which dust can collect. The grinding wheels and the floor around them should likewise be kept free from dust, preferably through the use of a suction exhaust system. If proper precautions are observed, the fire risk is small and if ignition should occur, the flame will be confined to a minimum of material. Regular molding sand will quickly extinguish any fire that does start. Graphite, table salt, or cast iron borings should be used in case of fire in the machine shop or around equipment that might be damaged by the abrasiveness of sand.

Welding and soldering of castings are not as common practices in the magnesium foundry as with some other metals, although these operations may be used to repair small surface defects

in unstressed sections of certain types of castings. In acetylene welding, the casting should be heated to 600 to 750° F. The filler rod should be of the same general composition as the casting and a flux should be used. (Dow Flux No. 45, Alcoa Flux No. 22, etc.). The completed welds should be thoroughly cleaned in the chrome-pickle solution (see below) to remove any adhering flux.

Castings to be soldered should be thoroughly cleaned by wire-brushing, chipping, or filing so as to present a clean surface to which the solder can bond. They are then preheated to 300 to 400° F. and the solder vigorously puddled with a sharp-pointed steel tool until it has alloyed with the magnesium. Suitable soldering materials include 90 per cent cadmium—10 per cent zinc or 60 per cent cadmium—30 per cent zinc—10 per cent tin. The former is less brittle but requires a somewhat higher temperature.

Painting is the most practical surface finish for magnesium castings where appearance and protection are important. Chemical finishes have been developed but they are more important as preliminary treatments for painting than as decorative coatings.

The successful painting of magnesium alloy castings offers no unusual difficulties where approved materials are used and good painting practice is observed. Oxide films and dirt are generally removed mechanically by sandblasting or wire brushing. Oil and grease are removed by washing with a solvent, such as carbon tetrachloride or gasoline, or are removed by treatment in hot alkaline cleaners. Cleaned castings are then given the chrome-pickle treatment. This consists of a ½ to 2-minute dip in an aqueous solution containing 1.5 lb. of sodium bichromate and 1.5 pints of concentrated nitric acid per gallon of solution. This bath becomes depleted on use but its efficiency can be restored by proper additions of bichromate and acid. The bath should be discarded after it has been rejuvenated four or five times. Upon removal from this bath, the castings are allowed to drain for a few seconds and then thoroughly washed in hot water. This treatment improves the corrosion resistance of the metal and gives an excellent "tooth" which increases the adhesion of subsequent paint coatings.

The selection of the primer is very important in view of the fact that all representatives of a given class of paints do not show

the same service performance. Vehicles with maximum adhesion and maximum imperviousness to water should be selected where service conditions are severe. Baking primers and finishes have excellent adhesion and are, therefore, recommended for small castings or wherever they can be applied. Zinc chromate primers meeting Navy Specification P-27 should be used on large castings in service near salt water or continuous moist air. The latter constitute the best all around primers and should be used where the type of service is unknown. The choice of surfacer and finish coats is likewise important although perhaps not so exacting. A good quality oil paint or enamel is satisfactory for interior work while full synthetic and oil-base synthetic enamels represent the better class of products for outdoor service or near the sea coast.

4. *Heat Treatment*

Most of the magnesium sand casting alloys now being used commercially are amenable to heat treatment with marked improvements in mechanical properties. Both the solution and the precipitation methods are used, depending on properties required. The solution heat treatment (H.T.) of the Mg-Al-Mn alloys consists of 16 hours heating at 775° F. followed by a quench. It increases the tensile strength, toughness, and percentage elongation of the alloys. The smaller percentage aluminum in the Mg-Al-Mn-Zn alloys permits the use of a lower temperature and this is desirable to avoid the hot-short temperature zone occasioned by the presence of zinc.

The aging or precipitation heat treatment (H.T.A.) is given to the solution heat treated material and is substantially complete after 16 hours at 350° F. This treatment raises the yield strength and hardness of the alloys with a lowering of ductility and toughness. Properties intermediate between those of the solution heat treated and the fully aged conditions can be obtained by giving the alloy a partial or short-time precipitation heat treatment. This partial aging is not used extensively, however, because of the practical difficulties encountered with furnace charges consisting of various sized castings with both thick and thin sections.

Accurate temperature control is very important, particularly with the solution heat treatment which is carried out at a temperature close to the softening point of the alloy. Electrically heated ovens equipped with automatic temperature control and

fans that give reversals in direction of the circulating atmosphere insure the proper temperature regulation.

5. *Defects, Their Causes and Prevention*

Most of the troubles encountered in the magnesium foundry are similar in nature and remedy to the corresponding difficulties met in the production of castings from other types of alloys. Where differences do exist, they can usually be traced directly or indirectly to the lightness and chemical reactivity of magnesium.

Dross in castings is usually due to the pouring of dirty metal (incomplete washing with flux); to improper or insufficient skimming action in the gates; to the use of few large rather than numerous small gates; and to high pouring temperatures.

Burned spots are generally due to insufficient sand addition agent or to wet and hard rammed sand. Such troubles are overcome by the addition of more protective agent to the heap or facing; by dusting sulphur on the surface of the mold; by surface drying the mold; or by the use of smaller gates so as to give a more uniform distribution of heat in the mold.

Blow-holes are usually caused by dirty metal, improper gating, or improperly prepared sand. Dirty metal is more viscous than clean metal and so retards the escape of entrapped gas. The gates should, therefore, be so arranged that the metal enters the mold with a minimum of turbulence and mechanical entrapping of gas. Hard rammed molds, particularly from wet sand, and wet or dirty chills may result in surface blows sometimes mistaken for shrinks.

Pin-hole porosity is closely associated with other troubles, such as dross, burns, and blows and is probably due to somewhat similar causes. The more important factors that aid in its elimination are the pouring of clean metal from a ladle held close to the mouth of the sprue; the use of properly tempered sand containing sufficient protective agent; and proper gating for maximum skimming and minimum agitation of the metal. Tilting and venting of molds, particularly for flat castings, often aids in the elimination of this defect.

Shrinks may appear as surface depressions or as porous spots. Shrinkage cavities seldom occur except in the case of very heavy sections. Surface shrinks can generally be eliminated by the use and proper placement of risers and chills; by a change in gating to permit a lower casting temperature and a more uniform feeding and solidification of the casting. Blows caused by the use of wet

or dirty chills or by hard rammed molds may be readily mistaken for surface shrinks.

Porous spots are those sections where shrinkage has resulted in a multitude of small, often microscopic, cracks rather than in the formation of a few large cracks or pronounced surface shrinks. These defects are aggravated by oxidation nitridation of the spongy metal, particularly during heat treating operations. These porous spots often penetrate a considerable distance toward the interior of the casting and appear as gray colored spots on fractured surfaces.

B. PROPERTIES AND APPLICATIONS

1. *Chemical Control Limits*

The strength characteristics of these alloys are determined primarily by their aluminum content. Small percentages of zinc are added to improve the corrosion resistance and certain physical

Table 1

MAGNESIUM ALLOY INGOT FOR REMELTING

Alloy	Magnesium Per Cent	Aluminum Per Cent	Manganese Min. Per Cent	Zinc Per Cent	Copper Per Cent	Cadmium Per Cent	Silicon Max. Per Cent	Other Impurities[1], Max. Per Cent
C–11	Remainder	8.0–9.0	0.18	—	0.04 max.	—	0.2	0.3
C–12	Remainder	9.4–10.6	0.13	—	0.04 max.	—	0.2	0.3
C–13	Remainder	11.5–12.5	0.13	—	0.04 max.	—	0.2	0.3
C–14	Remainder	5.5–6.5	0.18	2.7–3.3	0.04 max.	—	0.2	0.3
C–15	Remainder	1.7–2.3	0.20	—	3.3–4.7	1.7–2.3	0.2	0.3

[1] Nickel max. 0.02 per cent.

Table 2

MAGNESIUM ALLOY SAND CASTINGS

Alloy	Magnesium Per Cent	Aluminum Per Cent	Manganese Min. Per Cent	Zinc Per Cent	Copper Per Cent	Cadmium Per Cent	Silicon Max. Per Cent	Other Impurities[1], Max. Per Cent
C–11	Remainder	7.8–9.2	0.15	0.3 max.	0.05 max.	—	0.5	0.3
C–12	Remainder	9.0–11.0	0.10	0.3 max.	0.05 max.	—	0.5	0.3
C–13	Remainder	11.2–12.8	0.10	0.3 max.	0.05 max.	—	0.5	0.3
C–14	Remainder	5.3–6.7	0.15	2.5–3.5	0.05 max.	—	0.5	0.3
C–15	Remainder	1.5–2.5	0.15	0.3 max.	3.0–5.0	1.5–2.5	0.5	0.3

[1] Nickel, Max. 0.03 per cent.

properties, but the amount of zinc must be kept relatively low to avoid hot-shortness, particularly during heat treatment. The best combinations of properties are obtained with alloys containing 8 to 12 per cent of aluminum or of aluminum plus zinc. Alloys with less than 8 per cent of added metal have relatively poor casting characteristics and low yield strength and hardness, while alloys with more than 12 per cent of added metal are too brittle for most purposes.

Manganese should be present in all magnesium casting alloys in amounts ranging from 0.1 to 0.4 per cent, that is, in amounts approximating the solubility of manganese in the liquid alloy. These percentages of manganese have little to no effect on the physical properties of the alloys but very materially improve their corrosion resistance, particularly towards salt water.

Since copper and nickel have a very deleterious effect on the corrosion resistance, all metal handling operations, particularly remelting, must be carefully controlled so as to prevent contamination. Alloy C-15, however, purposely contains a large percentage of copper to yield a material with high thermal conductivity, but this advantage is gained at the sacrifice of corrosion resistance. Small amounts of silicon exert no appreciable effect on the corrosion resistance but as the percentage is increased, the alloys become more brittle.

2. *Physical Properties of Sand Castings*

Physical properties of sand castings are given in Table 3.

3. *Conforming Specifications*

Conforming specifications are given in Table 4.

4. *Development and Field of Use*

Magnesium alloy castings are used chiefly in those industries where lightness is essential, that is, where a saving in weight results in a more economical operation of equipment or in a saving of human fatigue. This lightness, coupled with good mechanical properties, gives magnesium alloys strength-weight ratios decidedly superior to those of most other casting alloys. Magnesium alloy castings lose their strength at elevated temperatures, and therefore, are best fitted for use at or near room temperature.

Substantially all magnesium alloy castings are now produced

Table 3

PHYSICAL PROPERTIES OF MAGNESIUM ALLOY SAND CASTINGS

Property	C-11 As Cast	C-11 H.T.	C-12 H.T.	C-12 H.T.A.	C-13 H.T.A.	C-14 As Cast	C-14 H.T.	C-14 H.T.A.	C-15 As Cast
Tensile Strength, lb. per sq. in. (Min. to Avg.)[1]	23,000 to 26,000	29,000 to 34,000	29,000 to 32,000	29,000 to 34,000	27,000 to 29,000	24,000 to 27,000	30,000 to 35,000	32,000 to 39,000	21,000 to 24,000
Yield Strength, lb. per sq in. (Perm. Set 0.2 per cent)	11,000	11,000	12,000	19,000	21,000	11,000	11,000	19,000	8,000
Modulus of Elasticity, lb. per sq. in. x 10^6	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Elongation, per cent in 2 inches (Min. to Avg.)	3-5	6-10	5-7	0-2	0-0.5	4-6	6-11	2-5	3-6
Brinell Hardness, 10 mm Ball, 500 kg. load	49	48	52	70	78	49	51	68	40
Compression Strength, lb. per sq. in.[2]	46,000	46,000	50,000	54,000	54,000	47,000	48,000	51,000	39,000
Specific Gravity	1.80	1.80	1.81	1.81	1.82	1.83	1.83	1.83	1.86
Weight per cu. in.—lb.	0.065	0.065	0.066	0.066	0.066	0.066	0.066	0.066	0.067
Pattern Makers Shrinkage, in. per ft.	3/16	3/16	3/16	3/16	3/16	3/16	3/16	3/16	3/16
Solidification Range, °F. (Approx.)	1120 to 815	1120 to 815	1100 to 815	1100 to 815	1070 to 815	1155 to 750	1155 to 750	1155 to 750	1185 to 1050
Electrical Resistivity, (Microhms per cm^3 at 20°C (68°F)	13.0	15.0	17.5	14.0	14.0	11.5	14.0	12.5	6.5
Endurance Limit, lb. per sq. in. (R. R. Moore Machine, 500 mil. rev.)	7000	7000	10,000	9000	9000	10,000	10,000	10,000	6,000
Coefficient of Thermal Expansion per °Fx10^6, (65-750°F)	16	16	16	16	16	16	16	16	16

[1] Tension values determined on standard ½-in. diameter A.S.T.M. separately cast specimens.

[2] Results of tests on specimens having an l/r ratio of 5. All specimens failed by shearing.

from the Mg-Al-Mn or the Mg-Al-Mn-Zn alloys. They are amenable to property improvement by solution heat treatment followed by precipitation heat treatment or aging. Three specific compositions of the Mg-Al-Mn series are being used commercially, the choice of alloy and heat treatment being dependent upon the properties necessary to meet the particular service requirements. Alloy C-12, with its various heat treatments, gives combinations of properties satisfactory for many purposes and, hence, is the most widely used of the three. Alloy C-11 is used where a combination of high tensile strength, percentage elongation, and toughness is required. Alloy C-13 is used in the precipitated or aged condition where maximum yield strength and hardness are desired, even at the expense of toughness.

The Mg-Al-Mn-Zn alloys are a more recent development and are being widely used now that they can be successfully heat treated. Alloy C-14 is the most widely used member of this series

and bids fair to replace the older Mg-Al-Mn alloys because it offers better combinations of mechanical properties with improved corrosion resistance. Some foundries are using it almost exclusively, while others are conducting extensive tests prior to its adoption. The as-cast properties are satisfactory for a large variety of uses while heat treated castings are used where service requirements demand maximum properties.

Alloy C-15 is a special composition with copper as the chief alloying ingredient. High thermal conductivity is its outstanding characteristic and it was developed primarily for use in pistons for internal combustion engines. The main functions of the other alloying ingredients is to improve its strength and foundry characteristics. The corrosion resistance of this alloy is much inferior to that of the other four magnesium casting compositions.

The aircraft industry is the largest consumer of magnesium alloy castings,—the more important applications including motor castings, starting equipment, instrument housings, landing wheels, and miscellaneous structural supports and brackets. The portable

Table 4

TRADE DESIGNATIONS OF CAST MAGNESIUM ALLOYS

Alloy	Condition	A. S. T. M.[1]	American Magnesium Corporation	Bohn Aluminum and Brass Corporation (Bohnalite)	Dow Chemical Company (Dowmetal)	U. S. Army[2]	U. S. Navy[3]
C–11	As Cast	Alloy 1	AM 241 C	X-5	A	—	1
	Solution Heat Treated	Alloy 1–H.T.1	AM 241 T4	X-5 H.T	A-H.T.	Grade 1	1a
C–12	Solution Heat Treated	Alloy 2–H.T.1	Am 240 T4	X-2 H.T	G-H.T.	—	2
	Solution Heat Treated and Aged	Alloy 2–H.T.3	Am 240 T61	X-2 H.T.A.	G-H.T.A.	Grade 2	2a
C–13	Solution Heat Treated and Aged	Alloy 3–H.T.3	AM 246 T6	—	B-H.T.A.	—	—
C–14	As Cast	Alloy 4	AM 265 C	X-8	H	—	5
	Solution Heat Treated	—	AM 265 T4	X-8 H.T.	H-H.T.	—	—
	Solution Heat Treated and Aged	—	AM 265 T6	X-8 H.T.A.	H-H.T.A.	—	—
C–15	As Cast	Alloy 5	—	X-4	T	—	3

[1] A.S.T.M. Spec. B80-34T (1934).
[2] U. S. Army Spec. 57-74-1B (1933).
[3] U. S. Navy Spec. M-112-c (1933).

tool industry is using increasing amounts of sand castings for handles, motor cases, and gear housings in both electric and pneumatic drills, sanders, and the like. Magnesium castings are likewise used in the reciprocating and rapidly moving parts of textile, packaging, and conveying machinery or equipment as well as in fans, blowers, and rotors. Safety device equipment includes tongs, saw guards, and safety blocks for forming presses. Foundry uses include flasks, pattern plates, core boxes, and core setting jigs.

Copper and Copper Manganese Gray Cast Iron*

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Abstract

This investigation reveals that copper alone increases hardness, compressive strength, and tensile strength, but has a slight adverse effect upon the transverse properties. The beneficial effects are most pronounced in iron containing about 1.5 per cent silicon or less. The copper promotes graphitization and decreases chill in low silicon iron, has no effect on these properties when the silicon is 2 per cent, and increases chill and retards graphitization slightly when the silicon is above 2.5 per cent. Both the fracture and graphite flakes are refined by the copper; the total shrinkage is increased slightly and red shortness is not augmented by the copper addition. Many other effects of copper are also reported in detail. The copper-manganese additions increase hardness, tensile strength, and compressive strength markedly and improve the transverse properties slightly in low alloy compositions; these beneficial effects are equally pronounced in low or high-silicon irons cast in green sand or dry sand. The effect on chill and graphitization is much like that of copper alone, but to a lesser degree. The total shrinkage is increased very slightly, both the fracture and graphite flakes are refined, the matrix of the 1.2-in. diameter bars is rendered sorbitic, and the red shortness is not increased by the copper-manganese (ratio approximately 1 to 1) addition. The results of the investigation are based upon (1) the production and testing of 120 compositions of gray iron to which only plain copper additions were made; and (2) the production of 110 compositions of copper-manganese gray iron of which the greater number have been completely tested.

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Note: This paper was presented at a session on Cast Iron at the 1936 Convention of A.F.A. in Detroit, Mich.

INTRODUCTION

1. This paper summarizes a manuscript dealing with the investigation into the use of copper in cast iron which was undertaken in the regular research program of the Michigan College of Mining and Technology and, during the past year, under the cooperative research program sponsored by the Federal Emergency Relief Administration.[1] It is a presentation of correlated data on the effects of copper in gray iron and a discussion of the properties of these alloys.[2]

2. A casual consideration of the complexity of cast iron alloys and of the importance of the many factors affecting the properties of cast iron, is sufficient to account for many of the discrepancies in work reported by numerous independent investigators in the literature. In view of this, the present investigation has been based upon a comprehensive plan which, in the study of the effect of copper, permits the control of the several variables of primary importance to the ultimate properties. Thus, the effect of copper on both dry sand and green sand castings was studied with controlled variation of silicon, carbon and manganese and with the other important factors held as constant as possible.

PRESENT INVESTIGATION

3. The present investigation began in 1932. The initial program was described in an editorial[3] which qualitatively discussed the general results obtained up to the time of publication. The scope of the project was later increased by the replacement of a 12-in. cupola with a 21-in. furnace having a capacity of approximately 1800 lb. per hour.

Obtaining a Suitable Base Iron

4. To obtain a uniform base-iron to which alloy additions could be made, a receiver was constructed and lined to a 21-in. inside

[1] The complete original manuscript may be obtained in mimeographed form for the cost of preparation, upon application to the Michigan College of Mining and Technology. It includes an historical summary and complete data in tabulated and graphical form together with photomicrographs. It further includes a careful study of the iron-copper and the iron-copper-cementite equilibrium diagrams in the light of previous investigations.

[2] For an historical review, a critical discussion and a bibliography consult original manuscirpt (See Note 1) and Gregg, J. L., and Daniloff, B. M., *"Alloys of Iron and Copper,"* Alloys of Iron Monograph Series, McGraw-Hill Book Co., New York (1934).

[3] Eddy, C. T., *"Copper in Gray Cast Iron,"* THE FOUNDRY, vol. 62, no. 2, February, 1934, p. 15.

diameter. A refractory lined cast iron cover was provided with a 4-in. opening to permit alloy additions to be made and to receive a high pressure oil burner which was used to preheat the receiver. Before the cupola was tapped, the burner was removed and the cover luted tightly into place.

5. Because the first charge was not as hot as the succeeding ones, scrap alone was used in it, the charge being tapped into the receiver and removed after a few minutes, just before the regular charge was tapped. About 800 to 900 lb. of the regular charge were then collected in the receiver, the cupola was closed down, and 5 or 6 taps were taken from the receiver with the various alloy additions made to each tap. A set of test bars was cast from each tap, the temperature of which was obtained by sighting a Leeds & Northrup optical pyrometer on the stream of iron tapped from the receiver. A second reading was made on the iron when the molds were poured. Since there was some temperature drop in the receiver, quadruplicate heats were made, two with copper added to the receiver, thus causing the copper content to increase with slightly decreasing casting temperature. In the other two heats, the copper was added to the ladle; the largest addition was made to the first tap, causing the copper content to decrease with slightly decreasing casting temperature. Thus each method of making the alloy addition was carried out in duplicate. This procedure was adopted to make possible the study of the effect of the slightly decreasing casting temperature.

Six Base Irons of Various Carbon and Silicon Contents

6. To determine the effect of copper in base-irons of various carbon and silicon contents, the following six types of charges were used, each being run in quadruplicate:

Type of Charge	Steel, Per Cent	Gray Iron Scrap, Per Cent	Pig Iron, Per Cent	Silicon, Per Cent
A	30	20	50	1.30
B	30	20	50	2.20
C	30	20	50	3.30
D	75	25	0	1.75
E	60	23	17	1.50
F	60	23	17	2.15

7. Group *C* contains somewhat higher silicon than most commercial gray irons. It was thought at the beginning that copper might overcome some of the undesirable features produced by high

silicon, but this possibility was not fulfilled. However, this high silicon iron, though of no probable commercial value, definitely has made it possible to substantiate the relationships of silicon to copper which were found in the lower silicon irons containing 1.3 and 2.2 per cent silicon.

8. It will be noticed that the base-iron contains a small amount of copper even though great care was exercised to keep it a minimum. Several probable sources of this copper are: (1) small amounts of copper frequently contained in local gray iron scrap; (2) copper absorbed from the linings of the furnace, forehearth and ladles; and (3) copper on the drill steel.

9. The most convenient size of local steel scrap is drill steel from the Upper Peninsula copper mines. This drill steel is hollow, and the mine water contains enough copper to plate out, principally on the interior of the steel where it would be less likely to be removed by wear entailed in the drilling operation and in handling.

10. The manganese was kept as constant as possible, 0.55 to 0.70 per cent, through the addition of spiegeleisen to the charge. The silicon content was controlled by using various grades of pig iron and by adding ferrosilicon to the charge. Because of the unavoidable differences in the composition of small charges, the silicon and manganese contents vary somewhat from the calculated percentages. The carbon content of the gray iron varied with the amount of carbon in the charge and with the silicon content, the latter tending to retard the carbon absorption in the cupola. The interval between successive cupola taps, about 6 minutes, was held as constant as possible to keep carbon absorption nearly constant.

11. Because of the relatively low carbon content of the type of charge represented by group *D* and the consequent lower melting rate of the charge and higher solidification temperature of the resulting iron, the receiver was not used, but instead, a 300 lb. ladle into which enough iron was tapped to cast two sets of test bars. The ladle additions were made and the process was twice repeated, producing 6 sets of test bars. A smaller ladle was used to pour the molds, the ladle addition being made in such a way that the quantity of copper addition was reversed, each method of addition being done in duplicate. Thus, the charge was run in quadruplicate, as were the others. The

analyses of group *D*, given in Table 1, show that there was some variation in the analysis of the base-iron. This was unavoidable, however, because of the difficulty of keeping this particular iron sufficiently hot for as long as 50 minutes, the time from the first cupola tap to the last receiver tap.

12. The results here reported were obtained from four or more heats for each base iron using six different irons of widely different compositions. These results will show that the conflicting nature of much of the data reported heretofore results from unduly general conclusions based on a very few heats having a very limited range in composition.

Test Bars.

13. The test bars cast consisted of (1) three bars, 1.2-in. diameter and 21-in. long cast in green sand, (2) three bars of the same dimensions cast in dry sand, (3) a step bar cast in green sand, (4) a chill block, (5) a bar to determine red shortness, and (6) a bar to determine total shrinkage. The outline of testing these bars is shown in the diagram, Fig. 1.

14. Each heat was numbered, each test bar being marked with this number and a letter, *A* to *E* or *F*, the *A* indicating the

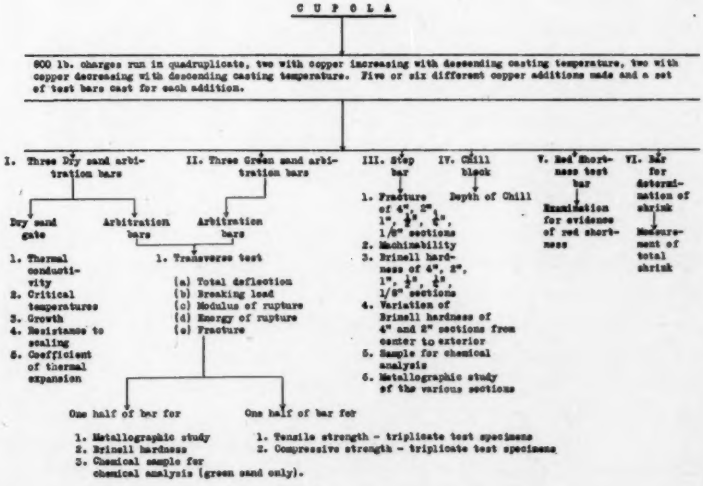
CUPOLA
800 lb. charges run in quadruplicate, two with copper increasing with descending casting temperature, two with copper decreasing with descending casting temperature. Five or six different copper additions made and a set of test bars cast for each addition.
I. Three Dry sand arbitration bars
II. Three Green sand arbitration bars
III. Step bar
IV. Chill block
V. Red Shortness test bar
VI. Bar for determination of shrink
Dry sand gate
Arbitration bars
Arbitration bars
1. Thermal conductivity
2. Critical temperatures
3. Growth
4. Resistance to scaling
5. Coefficient of thermal expansion
1. Transverse test
(a) Total deflection
(b) Breaking load
(c) Modulus of rupture
(d) Energy of rupture
(e) Fracture
1. Fracture
Depth of Chill
2. Machinability
3. Brinell hardness of 4", 2", 1", ½", ¼", 1/8" sections
4. Variation of Brinell hardness of 4" and 2" sections from center to exterior
5. Sample for chemical analysis
6. Metallographic study of the various sections
Examination for evidence of red shortness
Measurement of total shrink
One half of bar for
One half of bar for
1. Metallographic study
2. Brinell hardness
3. Chemical sample for chemical analysis (green sand only).
1. Tensile strength - triplicate test specimens
2. Compressive strength - triplicate test specimens

FIG. 1—OUTLINE OF TESTING PROCEDURE.

first set of test bars to be cast, and the last letter indicating the last set to be cast. The dry sand bars were given another letter, *D*, to indicate dry sand; the 1.2-in. diameter green sand bars were given a letter *G*. Thus, 36*CG* indicates heat 36, and a green sand bar of 1.2-in. diameter from the third set of test bars cast. Hence, the numbers of the specimens listed in the tables indicate the order in which specimens were cast during the respective heat. The analyses of the green sand and dry sand bars of the same set have the same composition. Complete analyses are given only in the tables listing the properties of the bars.

Methods of Casting Bars and Making Tests

15. The three green sand bars of arbitration-bar dimensions were cast horizontally. The pattern with gates and runners was mounted on a match board. The dry sand bars were cast vertically and gated at the bottom as shown in Figs. 2A and 2B. The gate, 3/4-in. in diameter, was saved for the purpose of determining thermal conductivity, coefficient of expansion, critical points, permanent growth, and resistance to scaling. The three dry sand bars and the three green sand bars were broken by transverse loading with an 18-in. span. From one of the halves of each bar, a standard tensile specimen and a compression specimen, 0.8-in. in diameter and 2.4-in. long, were machined. Hence, these specimens were tested in triplicate. At the beginning of the testing, the other three halves resulting from the transverse test were broken in impact, using an Amsler impact machine and an 8-in. span. This test was discontinued because the energy of rupture by the transverse test gave a better and more uniform indication of the brittleness than the energy of rupture by impact. This conclusion is based upon the fact that the energy of rupture by impact and the energy of rupture in transverse bending were similarly affected by the copper addition, thus showing their relationship and interdependence. The interdependence is natural, for each is a measure of the toughness of the iron. Because of the greater uniformity of the energy of rupture in the transverse test, this measure of the toughness of the iron was selected as being more satisfactory than that obtained by the impact test.

16. Total shrinkage was determined by casting a bar, as shown in Fig. 2C, between chills, 12 in. apart, and measuring the difference in length of the resulting bar and the length between chills.

17. Since copper is reported to cause red shortness, which would be a serious limitation if true, the possibility of such a characteristic was investigated by casting a clamp-shaped bar as illustrated in Fig. 2D. The piece of steel was inserted between the jaws of the clamp in such a position that the end of the steel

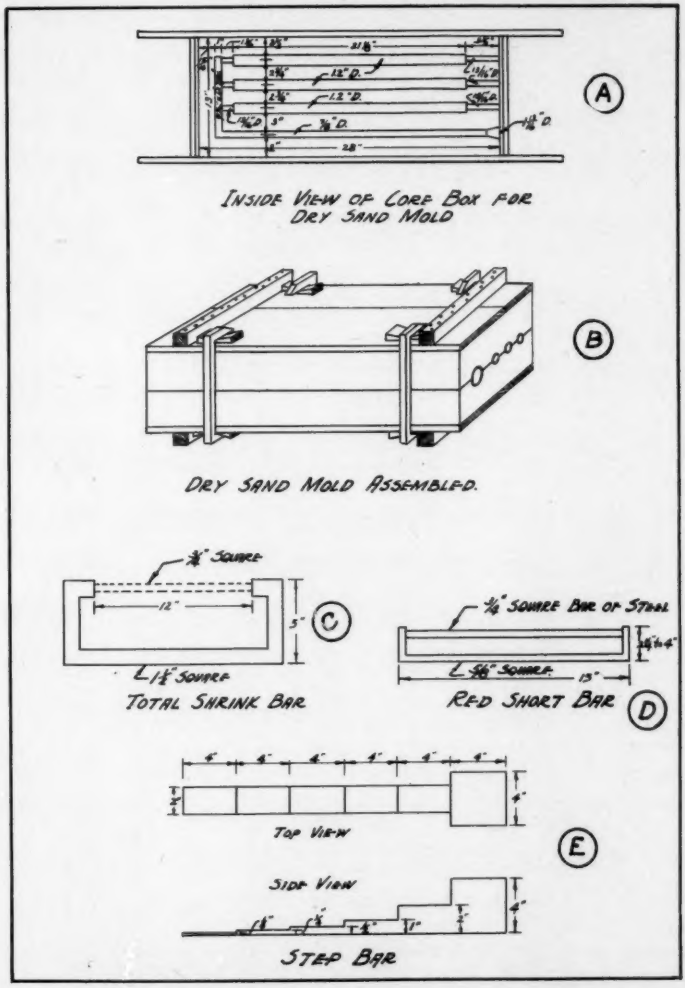

FIG. 2—A AND B—METHOD OF MOLDING TEST BARS. C—TOTAL SHRINKAGE BAR. D—BAR FOR TESTING RED SHORTNESS. E—STEP-BAR.

Table 1

ANALYSES AND PROPERTIES OF GREEN AND DRY SAND ARBITRATION BARS

No.	Analysis—Per Cent						Step Bar		Brinell Hardness		Tensile Strength lb. per sq. in.		Comp. Strength, lb. per sq. in.		Transverse Test Load—lb.		Transverse Test Deflection—in.		Mod. of Rupture lb. per sq. in.	
	Cu.	Si.	Mn.	P.	S.	C.	G.C.	C.C.	D[1]	G[2]	D[1]	G[2]	D[1]	G[2]	D[1]	G[2]	D[1]	G[2]	D[1]	G[2]
GROUP A																				
23A	0.11	1.21	0.59	0.22	0.08	3.46	2.75	0.71	....	200	.....	29,500	.....	107,440	.....	2360	.....	0.298	.....	62,700
23E	1.00	1.23	0.58	0.22	0.09	3.45	2.75	0.64	217	215	33,500	33,970	123,800	124,990	2360	2320	0.285	0.197	62,700	61,600
23B	1.15	1.23	0.58	0.22	0.08	3.45	2.75	0.70	222	222	34,500	35,500	116,040	114,280	2340	2370	0.263	0.241	62,000	56,200
23D	1.55	1.14	0.56	0.22	0.09	3.46	2.75	0.67	231	236	35,300	36,400	129,350	128,140	2180	2170	0.222	0.178	57,800	57,600
23C	2.10	1.19	0.54	0.23	0.09	3.47	2.72	0.68	241	236	38,500	36,300	123,850	119,700	2000	2375	0.206	0.227	53,000	63,000
24E	0.48	1.18	0.71	0.24	0.08	3.45	2.75	0.71	209	210	37,330	32,930	117,217	114,200	2420	2660	0.320	0.291	64,200	70,500
24C	0.78	1.13	0.66	0.22	0.10	3.52	2.75	0.79	216	219	37,000	34,430	117,570	114,130	2215	2507	0.315	0.288	58,800	66,500
24B	2.67	1.11	0.53	0.24	0.10	3.34	2.65	0.75	259	260	.....	36,430	124,150	127,133	....	2520	.....	0.228	.....	66,800
24A	3.05	1.12	0.51	0.24	0.10	3.25	2.46	0.73	255	255	38,950	42,030	134,325	126,900	2595	2530	0.232	0.217	65,500	65,700
24D	3.48	1.13	0.61	0.24	0.10	3.46	2.72	0.76	261	268	37,050	41,360	124,470	124,470	2300	2150	0.197	0.198	61,000	57,100
25A	0.23	1.29	0.56	0.25	0.09	3.38	2.72	0.66	211	206	33,600	33,500	117,830	115,400	2410	2380	0.288	0.284	63,900	63,200
25B	0.96	1.26	0.57	0.25	0.09	3.35	2.65	0.70	224	239	36,530	36,200	124,500	124,070	2500	2320	0.272	0.240	66,200	61,500
25C	1.60	1.25	0.56	0.26	0.09	3.35	2.60	0.75	243	247	38,800	37,000	125,430	124,770	2310	2310	0.246	0.221	61,200	61,300
25D	2.35	1.25	0.55	0.26	0.08	3.36	2.52	0.80	248	244	34,000	39,975	128,470	129,570	2020	2250	0.205	0.212	53,500	59,700
25E	3.10	1.26	0.57	0.26	0.08	3.37	2.45	0.90	255	251	37,530	39,230	132,470	133,170	2000	2210	0.202	0.195	53,000	58,700
38A	0.30	1.32	0.43	0.26	0.12	3.45	2.53	0.98	230	232	30,486	31,080	123,836	122,533	2420	2253	0.215	0.213	64,300	59,900
38B	1.07	1.36	0.45	0.26	0.11	3.46	2.55	0.96	255	254	32,580	35,280	133,330	129,166	1965	2210	0.170	0.182	51,800	58,600
38C	1.10	1.35	0.45	0.26	0.11	3.47	2.53	0.98	262	256	32,833	33,066	137,400	131,933	2063	2270	0.178	0.193	54,700	60,200
38D	3.06	1.35	0.45	0.25	0.11	3.35	2.41	0.88	277	265	30,720	31,320	135,200	128,590	1830	1945	0.161	0.179	49,000	51,500
38E	4.03	1.27	0.43	0.25	0.10	3.37	2.48	0.91	....	265	.....	23,344	.....	120,450	....	1760	.....	0.170	.....	46,600
39A	0.20	1.42	0.62	0.28	0.11	3.51	2.72	0.84	210	210	33,673	32,543	120,566	114,163	2380	2270	0.232	0.258	63,200	60,000
39B	2.09	1.36	0.58	0.28	0.10	3.50	2.72	0.82	252	246	34,286	38,606	129,766	131,233	2350	2193	0.220	0.198	62,300	58,000
39C	2.22	1.39	0.57	0.28	0.11	3.50	2.69	0.88	249	245	34,826	39,040	132,100	130,533	2110	2380	0.189	0.200	55,600	63,200
39E	2.50	1.39	0.58	0.27	0.11	3.49	2.60	0.95	239	242	35,350	.....	130,000	.....	2220	2413	0.185	0.232	58,800	63,300
39D	2.60	1.39	0.57	0.27	0.11	3.48	2.66	0.90	258	256	35,966	39,815	137,733	135,733	2073	2387	0.172	0.209	55,000	64,000
42E	0.25	1.50	0.48	0.26	0.09	3.59	2.90	0.70	196	187	29,100	28,366	108,666	106,833	2067	2193	0.246	0.282	54,800	58,200
42D	0.81	1.52	0.47	0.27	0.09	3.52	2.81	0.71	212	203	30,766	30,166	113,533	109,433	2130	2170	0.223	0.242	56,600	57,600
42C	1.48	1.43	0.47	0.27	0.09	3.46	2.79	0.68	222	212	32,000	30,766	118,966	110,900	2217	2357	0.220	0.247	53,600	62,500
42A	1.72	1.45	0.39	0.26	0.09	3.53	2.81	0.70	240	217	32,833	33,166	120,900	117,166	2185	2403	0.218	0.237	58,000	63,800
42B	3.05	1.46	0.44	0.25	0.09	3.48	2.80	0.71	241	238	35,700	35,900	125,633	124,526	2000	2370	0.193	0.230	53,000	62,900
GROUP B																				
26E	0.40	2.44	0.72	0.20	0.12	2.88	2.79	0.48	207	216	33,400	32,300	117,370	115,270	2160	2350	0.288	0.256	57,300	62,300
26C	1.84	2.31	0.72	0.16	0.10	2.88	2.68	0.55	230	246	35,200	35,900	122,600	122,410	2300	2380	0.249	0.232	61,000	63,200
26D	2.13	2.43	0.72	0.19	0.11	2.91	2.71	0.59	231	234	32,800	35,600	121,870	121,600	2150	2340	0.249	0.241	57,000	61,500
26B	2.81	2.41	0.70	0.18	0.11	2.89	2.60	0.60	241	243	34,000	35,600	119,830	126,270	2123	2400	0.245	0.240	54,500	63,700
26A	3.05	2.36	0.71	0.17	0.11	3.22	2.55	0.62	239	246	33,800	36,550	116,800	128,970	2150	2290	0.254	0.215	57,500	60,700
27A	0.16	2.49	0.66	0.25	0.11	3.21	2.65	0.58	212	212	33,000	35,000	113,430	121,270	2340	2480	0.274	0.273	62,100	65,700
27B	0.83	2.55	0.65	0.26	0.12	3.16	2.63	0.60	231	226	34,970	35,800	122,730	125,400	2230	2320	0.239	0.234	51,900	61,700
27C	1.54	2.51	0.65	0.27	0.11	3.15	2.65	0.63	238	239	35,600	36,800	125,130	126,370	2360	2340	0.257	0.230	62,000	62,100
27D	2.46	2.51	0.63	0.26	0.10	3.16	2.50	0.65	237	246	32,800	34,700	119,200	127,770	....	2215	.....	0.231	.....	58,800

27E	3.36	2.48	0.62	0.26	0.10	3.11	2.41	0.69	254	254	35,200	37,350	130,100	130,200	2115	2210	0.223	0.209	56,100	58,500
40A	0.38	2.59	0.56	0.26	0.10	3.41	2.61	0.95	218	212	33,366	32,166	12C,633	116,260	2280	2430	0.270	0.291	60,500	64,500
40B	0.89	2.56	0.58	0.26	0.10	3.32	2.56	0.98	237	220	33,233	34,066	124,290	123,893	2138	2420	0.226	0.251	56,700	64,200
40C	1.56	2.52	0.58	0.26	0.10	3.44	2.56	1.01	249	234	34,160	34,966	126,533	124,500	2247	2397	0.218	0.238	59,700	63,600
40D	2.44	2.50	0.57	0.26	0.10	3.41	2.59	1.00	255	249	37,533	37,466	128,526	127,366	2335	2430	0.199	0.224	62,000	64,500
40E	3.74	2.46	0.59	0.26	0.10	3.36	2.60	0.95	260	253	34,166	34,933	132,900	128,300	2190	2453	0.230	0.232	59,500	65,100
41E	0.17	2.36	0.42	0.29	0.08	3.30	2.56	0.68	207	207	29,700	30,733	112,800	112,333	2233	2480	0.267	0.298	59,300	65,800
41D	0.87	2.33	0.42	0.29	0.08	3.25	2.52	0.69	220	221	32,233	33,133	118,900	115,580	2180	2410	0.233	0.254	57,800	64,000
41C	1.78	2.33	0.41	0.29	0.08	3.20	2.54	0.69	228	228	34,366	33,700	124,900	120,566	2203	2427	0.243	0.246	58,500	64,400
41B	2.47	2.33	0.40	0.29	0.08	3.17	2.41	0.71	235	235	30,603	34,330	123,226	121,100	2120	2177	0.240	0.219	58,000	59,600
41A	2.73	2.32	0.39	0.28	0.08	3.14	2.42	0.73	241	241	35,233	35,033	124,833	124,466	2180	2377	0.222	0.229	58,800	63,100
GROUP C																				
28A	0.38	2.60	0.69	0.24	0.12	2.97	2.65	0.48	217	219	33,016	36,876	120,380	122,270	2070	2490	0.214	0.256	54,400	66,300
28B	0.95	2.80	0.67	0.25	0.11	2.99	2.44	0.50	226	224	29,440	32,160	111,650	115,330	2030	2140	0.223	0.239	53,400	56,800
28C	2.13	3.40	0.66	0.25	0.10	2.91	2.42	0.50	230	229	29,866	25,212	116,750	105,130	1820	1680	0.225	0.201	48,200	44,600
28D	3.00	3.35	0.65	0.24	0.10	2.92	2.41	0.54	248	239	26,636	25,480	115,470	108,850	1760	2106	0.221	0.247	46,500	54,600
28E	4.60	3.30	0.64	0.23	0.10	2.92	2.42	0.58	228	230	23,686	22,220	105,170	101,000	1480	1670	0.193	0.209	39,200	44,200
29E	0.43	3.41	0.64	0.23	0.10	3.06	2.31	0.64	204	211	29,410	28,026	107,700	102,670	2010	2770	0.297	0.263	53,300	54,900
29D	1.04	3.31	0.62	0.23	0.10	3.02	2.36	0.64	219	222	29,346	27,893	107,720	103,500	1810	1830	0.230	0.215	47,900	48,400
29C	1.64	3.33	0.63	0.23	0.11	2.96	2.42	0.64	223	228	27,312	27,860	108,700	107,830	1966	2070	0.249	0.254	51,900	54,900
29B	3.06	3.16	0.61	0.23	0.11	3.05	2.48	0.69	235	241	27,840	29,766	109,550	112,350	2020	1980	0.255	0.199	53,500	52,500
29A	4.02	3.24	0.61	0.24	0.11	3.00	2.50	0.70	...	241	.....	.....	.....	117,350	....	2140	.....	0.243	.....	56,800
43E	0.24	3.94	0.55	0.24	0.09	3.08	2.50	0.54	200	199	22,716	22,350	91,850	91,270	1780	1737	0.229	0.203	45,800	46,000
43D	1.20	3.90	0.53	0.25	0.09	3.02	2.46	0.51	199	208	23,150	22,516	97,930	94,700	1723	1617	0.226	0.191	45,600	42,800
43C	2.05	3.79	0.53	0.25	0.09	3.08	2.48	0.60	204	207	23,148	24,308	98,770	100,270	1807	1500	0.226	0.180	47,800	39,800
43A	2.88	2.53	0.59	0.25	0.09	3.11	2.53	0.59	241	245	35,950	33,933	127,170	127,170	2160	2160	0.196	0.212	57,300	57,200
43B	3.08	2.97	0.55	0.25	0.09	3.03	2.50	0.52	220	218	27,900	24,508	116,170	106,430	1730	1913	0.208	0.213	45,900	50,700
44A	0.59	4.27	0.54	0.19	0.09	3.05	2.48	0.56	212	206	20,536	19,613	84,533	83,600	1395	1340	0.173	0.156	37,000	35,500
44B	1.59	4.71	0.56	0.19	0.08	3.00	2.50	0.60	217	226	20,666	.....	91,566	90,100	1590	1840	0.250	0.235	42,200	48,700
44C	2.36	4.68	0.54	0.19	0.07	3.08	2.60	0.61	228	228	20,670	18,260	94,033	88,400	1557	1600	0.239	0.214	41.300	42,500
44D	3.64	4.58	0.54	0.19	0.07	3.10	2.55	0.55	222	212	19,733	.....	95,550	96,633	1415	1615	0.217	0.276	37,600	42,900
44E	3.79	4.61	0.54	0.19	0.07	2.91	2.41	0.53	209	210	19,406	18,285	91,566	92,233	1583	1467	0.226	0.218	42,000	38,900
GROUP D																				
56A	0.56	1.87	0.52	0.07	0.14	2.89	2.19	0.70	283	277	51,850	51,600	165,450	166,300	3197	3117	0.236	0.232	78,200	81,600
56C	1.30	1.57	0.43	0.03	0.14	3.02	1.95	1.07	299	296	58,475	57,166	176,300	175,250	3123	3243	0.229	0.239	82,300	85,300
56B	1.48	1.86	0.60	0.07	0.14	2.87	1.98	0.89	302	286	.....	47,633	.....	170,300	....	2913	.....	0.197	.....	77,400
56D	2.48	1.58	0.42	0.03	0.13	2.99	2.00	0.99	308	302	59,150	58,600	176,166	181,316	3302	2973	0.257	0.218	87,600	78,000
56E	2.79	1.84	0.52	0.03	0.12	2.94	1.93	1.01	314	321	58,100	59,450	178,800	180,000	3263	2981	0.249	0.217	75,700	82,400
56F	3.95	1.79	0.52	0.03	0.12	2.89	2.03	0.86	318	321	57,160	62,650	183,950	177,383	2802	2810	0.220	0.210	74,000	73,800
57A	0.67	1.66	0.39	0.04	0.12	2.95	2.01	0.94	...	276	.....	61,000	.....	166,900	....	3408	.....	0.272	.....	89,600
57B	1.31	1.68	0.50	0.04	0.12	2.95	2.03	0.92	293	299	59,500	64,700	174,800	179,450	3185	3261	0.220	0.226	84,200	84,700
57C	1.90	1.61	0.53	0.03	0.12	2.85	1.93	0.92	286	299	61,780	62,250	169,500	172,650	3160	3778	0.243	0.269	83,200	99,300
57E	3.16	1.69	0.50	0.03	0.11	3.10	2.24	0.86	...	302	.....	55,800	.....	.....	....	3178	.....	0.262	.....	84,400
57D	3.60	1.57	0.53	0.03	0.12	2.89	2.02	0.87	308	308	61,933	53,500	178,430	176,000	2760	....	0.211	.....	72,800	.....
57F	5.34	1.59	0.45	0.03	0.11	3.08	2.23	0.85	286	292	47,400	49,120	164,100	167,830	2533	2778	0.214	0.224	67,100	72,700
58F	0.24	1.49	0.41	0.04	0.11	2.86	1.82	1.04	257	269	57,000	57,400	158,900	167,900	3486	3201	0.273	0.197	92,800	84,600

[1] Dry Sand Bar.
[2] Green Sand Bar.

(*Continued on page 60*)

Table 1 (Continued)

ANALYSES AND PROPERTIES OF GREEN AND DRY SAND ARBITRATION BARS

Analysis—Per Cent							Step Bar		Brinell Hardness		Tensile Strength lb. per sq. in.		Comp. Strength, lb. per sq. in.		Transverse Test Load—lb.		Transverse Test Deflection—in.		Mod. of Rupture lb. per sq. in.	
No.	Cu.	Si.	Mn.	P.	S.	C.	G.C.	C.C.	D[1]	G[2]	D[1]	G[2]	D[1]	G[2]	D[1]	G[2]	D[1]	G[2]	D[1]	G[2]
GROUP D (Continued)																				
58E	2.38	1.49	0.47	0.04	0.13	2.85	1.86	0.99	296	299	60,000	59,100	176,000	176,900	3230	3182	0.241	0.218	85,700	84,500
58D	3.39	1.75	0.53	0.04	0.14	2.74	1.90	0.84	321	308	66,000	63,800	181,800	182,800	3532	3275	0.252	0.226	93,800	70,800
58C	4.36	1.70	0.51	0.05	0.11	2.75	1.86	0.89	311	318	53,900	57,900	175,630	177,800	3472	3337	0.261	0.217	91,800	88,600
58B	4.70	1.51	0.43	0.06	0.12	2.69	1.77	0.92	308	308	44,000	48,600	173,300	173,850	....	3055	.....	0.223	.....	81,000
58A	5.96	1.53	0.35	0.06	0.10	2.67	1.82	0.85	...	313	42,200	47,050	173,530	170,000	....	2950	.....	0.227	.....	77,700
59F	0.20	1.61	0.62	0.05	0.10	3.22	2.43	0.79	241	255	48,700	49,400	142,100	149,300	3007	3043	0.286	0.269	79,200	79,800
59E	0.90	1.50	0.53	0.04	0.11	3.21	2.43	0.78	262	269	51,100	52,700	147,300	154,700	3020	3258	0.273	0.265	80,100	83,900
59D	2.00	1.75	0.40	0.04	0.10	2.97	2.23	0.74	256	293	57,300	59,300	167,500	164,200	3060	3282	0.238	0.237	81,200	87,100
59C	3.56	1.67	0.64	0.04	0.10	2.99	2.14	0.85	303	308	58,300	56,900	163,850	168,600	2957	3249	0.247	0.256	78,300	86,300
59B	4.61	1.71	0.52	0.05	0.13	2.87	1.93	0.94	308	319	55,200	53,970	169,500	172,130	2736	2816	0.218	0.220	72,100	74,800
59A	5.88	1.73	0.42	0.05	0.13	2.80	1.95	0.85	313	314	51,800	52,900	168,100	177,800	2441	3700	0.200	0.219	68,500	71,500
GROUP E																				
30A	0.20	1.57	0.65	0.17	0.12	3.10	2.34	0.76	217	219	40,420	37,966	135,250	127,970	2340	2560	0.251	0.278	62,000	68,200
30B	1.25	1.43	0.64	0.16	0.12	3.10	2.39	0.71	247	242	39,590	40,686	138,270	138,100	2540	2580	0.253	0.259	67,500	68,500
30C	2.30	1.47	0.64	0.16	0.12	3.15	2.39	0.76	269	271	39,223	42,240	146,470	145,600	2520	2570	0.238	0.230	66,900	68,100
30D	3.55	1.53	0.64	0.16	0.12	3.16	2.40	0.76	277	277	41,212	41,212	149,030	149,030	2490	2570	0.227	0.221	66,200	68,200
30E	5.08	1.47	0.63	0.17	0.10	3.12	2.33	0.69	286	285	38,523	38,200	153,770	154,170	2130	2170	0.211	0.202	56,600	57,500
31E	0.17	1.53	0.58	0.19	0.10	3.10	2.37	0.73	231	241	40,570	39,732	135,533	137,700	2563	2647	0.272	0.267	68,000	66,000
31D	1.75	1.55	0.58	0.18	0.11	3.06	2.34	0.70	260	260	47,283	...	146,800	.....	2750	2533	0.270	0.239	73,200	67,300
31C	2.65	1.52	0.59	0.19	0.10	3.04	2.19	0.85	270	273	40,950	40,803	152,666	152,633	2483	2477	0.236	0.225	66,900	65,800
31B	3.25	1.51	0.57	0.18	0.11	3.05	2.22	0.83	286	286	42,223	45,390	151,733	156,566	2410	2500	0.227	0.206	64,000	66,400
31A	4.09	1.45	0.56	0.18	0.11	2.98	2.15	0.83	280	283	41,935	37,200	151,800	155,700	2161	2403	0.230	0.212	57,200	63,600
32A	0.55	1.65	0.57	0.17	0.12	3.05	2.61	0.44	251	250	46,003	43,346	140,533	145,333	2710	2643	0.275	0.249	72,800	69,100
32B	1.67	1.63	0.58	0.17	0.12	2.99	2.50	0.49	269	277	41,105	45,560	149,330	149,200	2643	2523	0.245	0.206	70,100	66,600
32C	2.62	1.57	0.57	0.16	0.12	3.03	2.48	0.55	291	297	44,807	46,923	155,900	163,400	2453	2625	0.220	0.233	65,100	70,200
32D	2.98	1.59	0.57	0.17	0.13	3.04	2.45	0.59	291	302	42,716	42,650	153,033	162,600	2695	2620	0.228	0.212	71,400	69,500
32E	4.71	1.55	0.55	0.17	0.12	2.99	2.37	0.64	295	302	34,950	39,052	150,933	153,000	2173	2387	0.206	0.217	57,700	63,300
34E	0.50	1.61	0.72	0.19	0.11	3.15	2.39	0.76	241	254	41,560	39,083	141,866	141,566	2550	2480	0.291	0.251	67,700	65,800
34D	2.56	1.61	0.69	0.18	0.10	3.11	2.37	0.74	277	266	43,500	45,633	152,333	152,600	2533	2527	0.254	0.233	67,300	67,000
34C	2.60	1.57	0.68	0.19	0.10	3.15	2.26	0.89	286	291	43,833	43,730	154,466	154,333	2430	2527	0.238	0.237	64,500	67,100
34B	3.42	1.57	0.68	0.19	0.10	3.14	2.37	0.77	287	286	44,176	39,970	153,200	153,100	2543	2380	0.240	0.223	67,400	63,100
34A	3.85	1.57	0.67	0.18	0.10	3.17	2.45	0.72	286	291	38,500	43,536	155,566	155,000	2203	2267	0.203	0.213	58,400	61,100
36A	0.43	1.12	0.67	0.10	0.13	3.29	2.37	0.92	239	237	41,690	43,176	138,400	136,266	3030	2807	0.297	0.253	80,500	74,400
36B	1.61	1.10	0.64	0.18	0.12	3.30	2.39	0.91	264	269	43,406	46,000	144,066	146,533	2793	2880	0.234	0.217	75,300	76,300
36C	2.30	1.08	0.64	0.19	0.12	3.22	2.30	0.92	270	283	43,276	45,243	152,233	152,066	2963	2700	0.233	0.218	78,600	71,600
36D	3.85	1.07	0.62	0.19	0.12	3.22	2.29	0.93	296	302	40,045	44,960	162,366	159,766	2565	2377	0.209	0.183	68,600	63,100
36E	5.31	1.04	0.58	0.18	0.12	3.22	2.26	0.96	297	304	34,526	39,200	152,033	160,900	2130	2270	0.170	0.180	56,500	60,300
37E	0.63	1.51	0.77	0.20	0.13	3.16	2.48	0.68	241	249	34,726	37,570	141,933	137,133	2543	1760	0.224	0.170	65,100	72,300
37A	1.78	1.46	0.73	0.20	0.13	3.22	2.45	0.77	265	269	39,230	44,393	149,366	148,100	2823	2253	0.233	0.213	74,800	74,000
37D	3.85	1.45	0.73	0.20	0.19	3.20	2.31	0.89	284	287	35,100	38,016	147,000	153,933	2520	1945	0.209	0.179	65,800	65,800

Table 1 (Continued)

GROUP E (Continued)																				
37B	5.55	1.40	0.72	0.20	0.19	3.17	2.31	0.86	287	296	37,700	38,488	150,566	156,300	2375	2210	0.192	0.182	63,100	60,500
37C	5.85	1.41	0.69	0.19	0.19	3.14	2.26	0.88	285	285	34,800	37,166	150,100	152,666	2270	2270	0.179	0.193	60,200	63,200
GROUP F																				
33A	0.36	1.93	0.67	0.17	0.10	3.17	2.45	0.76	229	239	35,693	43,286	141,300	140,233	2380	2647	0.267	0.267	63,100	70,200
33B	1.16	2.24	0.65	0.18	0.10	3.09	2.45	0.76	247	246	39,060	40,938	144,600	141,833	2243	2537	0.243	0.263	59,400	67,300
33C	2.16	2.23	0.65	0.18	0.10	3.07	2.45	0.74	272	269	37,496	42,533	147,500	147,133	2413	2610	0.223	0.267	63,900	69,300
33D	3.13	2.19	0.65	0.18	0.10	3.10	2.45	0.74	278	286	35,336	43,916	154,366	155,966	2493	2483	0.241	0.235	66,100	65,900
33E	4.64	2.19	0.62	0.17	0.10	3.15	2.39	0.76	279	287	35,764	38,900	146,300	152,466	1997	2397	0.212	0.236	52,900	63,500
35E	0.63	2.22	0.64	0.19	0.11	3.00	2.29	0.94	257	256	43,128	46,376	145,333	144,300	2765	2820	0.250	0.247	73,300	74,700
35D	3.26	2.28	0.61	0.19	0.10	2.93	2.29	0.88	286	296	44,353	46,083	156,666	156,000	2860	2697	0.216	0.213	75,800	71,500
35C	3.90	2.26	0.60	0.18	0.10	2.97	2.29	0.73	294	294	40,786	45,470	157,366	159,633	2847	2677	0.226	0.216	75,500	71,000
35B	5.23	2.21	0.56	0.18	0.10	2.95	2.23	0.79	292	293	38,485	42,086	152,400	157,433	2177	2210	0.197	0.180	57,700	58,600
35A	5.55	2.22	0.55	0.18	0.11	2.93	2.18	0.81	279	288	.....	39,573	.....	159,866	1870	2403	0.168	0.206	49,500	63,800
60A	0.30	2.26	0.70	0.13	0.11	2.95	2.14	0.54	241	248	43,950	42,220	142,200	142,100	2632	2631	0.254	0.250	68,500	68,600
60B	1.32	2.28	0.68	0.13	0.11	2.90	2.34	0.56	269	269	46,390	43,600	154,500	142,900	2769	2567	0.246	0.225	73,400	69,800
60C	2.10	2.25	0.67	0.13	0.11	2.83	2.31	0.52	269	277	45,100	44,350	146,200	153,900	2580	2558	0.225	0.208	72,000	67,900
60D	3.18	2.19	0.64	0.12	0.11	2.74	2.27	0.47	286	301	36,300	43,500	156,900	156,000	2695	2519	0.230	0.204	71,600	67,000
60E	3.74	2.18	0.63	0.12	0.11	2.93	2.26	0.67	286	288	37,200	40,320	152,800	155,300	2300	2227	0.194	0.189	61,100	59,400
60F	4.00	2.18	0.63	0.12	0.11	2.82	2.28	0.54	287	294	37,500	36,550	153,900	154,800	2200	2277	0.196	0.199	58,500	60,500
61F	0.48	2.17	0.67	0.11	0.11	2.98	2.42	0.56	238	241	43,650	43,650	139,300	144,600	2675	2667	0.259	0.244	61,000	71,000
61E	0.52	2.18	0.67	0.11	0.11	2.98	2.30	0.68	237	249	43,350	43,720	142,200	141,000	2603	2379	0.253	0.221	69,100	65,700
61D	1.91	2.22	0.60	0.10	0.11	2.90	2.07	0.83	266	272	43,640	46,590	152,800	159,500	2487	2487	0.215	0.215	66,000	68,500
61C	2.76	2.25	0.65	0.10	0.11	2.87	2.24	0.63	272	277	44,040	45,540	149,500	152,900	2640	2320	0.233	0.219	70,000	66,500
61A	3.76	2.14	0.66	0.11	0.11	2.85	2.14	0.71	286	286	40,020	45,830	151,800	163,500	2539	2113	0.219	0.169	67,800	56,300
61B	4.02	2.18	0.64	0.11	0.11	2.91	2.26	0.65	280	291	43,550	42,360	149,400	156,100	2530	2097	0.221	0.176	67,000	56,000

[1]Dry Sand Bar
[2]Green Sand Bar

bar and the clamp were in contact, thus preventing shrinkage. The strain at the corners of the hot iron should cause failure by cracking if the copper bearing iron were hot short.

18. The step-bar, illustrated in Fig. 2E, was designed to give information on the effect of copper upon the formation of free cementite, and upon the fracture and hardness of the various sections. The 4-in. sections and the 2-in. sections were cut through the center to permit an investigation of the variation in hardness from the center to the exterior of the section.

19. The chill blocks, 4-in. long, 2-in. high, and 1-in. thick, were cast on edge on an iron chill. After cooling, the blocks were broken in two parts and the depth of chill was measured.

Chemical Compositions

20. Chemical compositions of the irons tested are based on analyses of two sets of samples, one taken from the 1.2-in. diameter green sand bar and the other from the 2-in. section of the step-bar. When casting, the step-bar was poured first, the dry sand bars second, the 1.2-in. diameter green sand bars third, the red shortness bar and the total shrink bar fourth, and the chill block last. Hence, the samples for chemical analyses were taken from two portions of the iron in the same ladle, one from the first iron poured and the other from the iron poured from the last portion of the metal. The analyses of the plain copper cast iron are given in Table 1.

METHODS OF ADDING COPPER TO CAST IRON

21. There are several methods of adding copper to cast iron:

(1) Direct addition of copper ingots or other suitable forms to the cupola, either as pigs added directly with the charge or enclosed in cast iron. This method has the advantage of simplicity. However, behavior in the cupola and the losses have not been sufficiently investigated.

(2) The melting of copper bearing scrap in the cupola. At least part of the copper can be added in this manner, as no difficulty from melting copper-bearing gray iron scrap was experienced.

(3) The addition of copper turnings or shot, cold or heated, to the iron issuing from the spout when tapping the cupola. Copper melts at 1083 deg. C. (1981 deg. F.), and, as compared with nickel, it melts readily and is quickly dis-

solved by the iron. Under the usual conditions, at least 1.5 per cent of copper can be added by dropping copper shot into the tapped stream of iron. The maximum amount of copper which can be added depends upon the temperature and composition of the iron tapped from the cupola and the minimum permissible casting temperature. Three per cent copper has been successfully added by tapping the heat into a small ladle in which 25-lb. copper ingots were placed. The ladle was held at such an angle that it continuously poured into the larger receiving ladle. The copper was thus dissolved by the hot metal and washed into the forehearth or receiving ladle, the agitation due to the pouring assuring uniform mixture.

(4) Addition of copper in the molten state to the iron as tapped from the cupola. This method is the best when high percentages of copper are added to the iron.

(5) Addition of copper in the form of a copper-silicon alloy, either cold, hot, or molten. When copper is melted with 90 per cent grade ferrosilicon to form an alloy containing 8 to 15 per cent silicon, the resulting alloy melts at 800 to 850 deg. C. (1472 to 1562 deg. F.) as compared with 1083 deg. C. (1981 deg. F.) for pure copper. This alloy is readily dissolved, forming a uniform alloy cast iron. Of course, the added silicon must be taken into consideration. This method yielded excellent and uniform results, but because of the added variable, silicon, this type of alloy addition is not suitable for research.

(6) Addition of copper in the form of a copper-manganese alloy, either cold, hot, or molten. When standard ferromanganese is added to molten copper, the ferro-alloy dissolves and the graphite liberated forms a "kish." The resulting alloy, when containing 20 to 45 per cent manganese, melts at 875 to 925 deg. C. (1607 to 1697 deg. F.) and is also ideal for alloying additions. High manganese-copper gray iron was investigated in the research project here reported. In some instances, when the manganese was added to the cupola and the molten copper to the tap, the iron was found to be unsound. However, when the molten copper-manganese alloy, containing about 35 per cent manganese, was added to the ladle or forehearth, the resulting alloy cast

iron was both uniform and sound. The alloy addition must be made to the ladle or forehearth with simultaneous stirring to avoid settling to the bottom and consequent difficulty of solution.

PLAIN COPPER GRAY IRON

22. The data obtained on the properties of the plain copper gray iron are listed in Tables 1 and 2 along with the chemical analysis. The various properties have been plotted against the copper content for all of the heats, being grouped in accord with the six base mixes used. For the purpose of this summary however, the resulting number of figures was prohibitive, and Fig. 3 is given merely to indicate the general nature of the influence of copper on the properties concerned.

23. It is obviously not a rigorous representation nor can such be derived from the data for several reasons: small inconsistencies in the properties, variations in analysis (in quadruplicate heats) because of the difficulty of obtaining small charges of the same composition, and deliberate and statistical variation in foundry technique (additions made on rising temperature, on falling temperature, to the forehearth, to the ladle, etc.). For the purpose of comparison, the data from one heat, picked as representative of each group, are plotted in dashed lines on the same coordinates (Fig. 3). Because the beneficial effects of copper in high-silicon irons are minimum and because erratic results were obtained in the testing of these irons, the curve for group *C* is omitted from Fig. 3.

Hardness

24. Fig. 3C shows the increase in hardness incident to the addition of copper. The figure and the actual data (Table 1) show an increase in hardness of about 30 to 60 points Brinell, the increase being somewhat greater for the lower-silicon and the lower-carbon irons, the silicon having the greater influence. When the silicon is high, as represented in group *C*, the results are erratic and the improvement of hardness is a minimum. The lower-carbon series, represented by groups *D*, *E*, and *F*, contain copper up to 5.5 per cent with gradually increasing hardness. This shows that the effective hardening copper—*i.e.*, that in supersaturated solution or as submicroscopic particles—can be present to the extent of 5.5 per cent. However, the maximum rate of

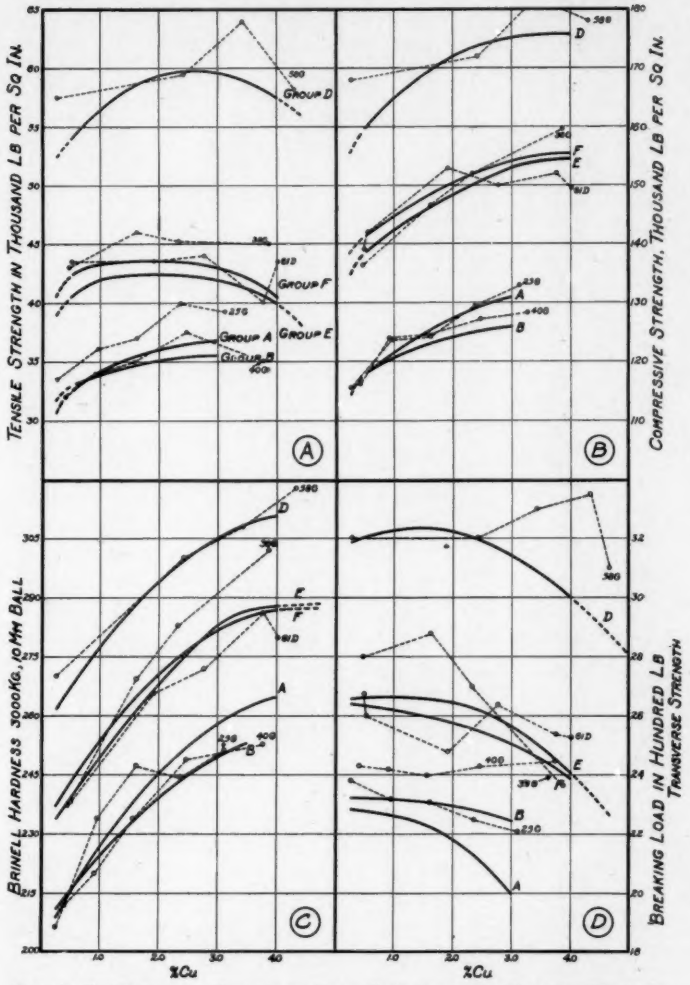

FIG. 3—INFLUENCE OF COPPER ON GRAY CAST IRON. A—TENSILE STRENGTH. B—COMPRESSIVE STRENGTH. C—BRINELL HARDNESS. D—TRANSVERSE STRENGTH.

increase in hardness occurs up to 3.0 per cent copper, after which it slopes off to some extent.

25. The study of the effect of copper on the Brinell hardness of the 1.2-in. diameter round bars reveals that when the silicon is approximately 1.3 per cent, each per cent of copper

Table 2

STEP BAR BRINELL HARDNESS

GROUP A

No.	Step Bar Section Thickness—in.						
	4[1]		2	1	½	¼	⅛[2]
	Int.	Ext.					
23A	175	196	199	229	225	286	48.5
23E	196	206	222	242	251	260	51.3
23B	194	211	215	255	245	263	47.8
23D	199	215	221	271	263	281	35.4
23C	210	224	229	262	278	287	49.3
24E	183	203	204	217	237	253	46.1
24C	180	192	208	224	233	248	53.9
24B	217	239	243	278	296	301	51.8
24A	235	249	259	280	297	...	42.5
24D	207	228	248	280	284	306	42.2
25A	170	191	201	220	230	246	51.5
25B	185	200	214	237	248	265	49.7
25C	192	216	224	256	264	282	47.1
25D	196	223	239	264	280	293	42.5
25E	207	235	244	276	292	312	42.2
38A	195	216	210	239	248	287	51.4
38B	202	226	223	257	273	295	53.6
38C	202	226	227	270	283	304	54.1
38D	207	240	232	273	284	325	57.1
38E	225	241	231	272	290	332	55.0
39A	171	196	192	226	239	252	32.7
39B	196	223	219	264	277	293	43.8
39C	206	221	219	266	284	297	32.9
39E	198	223	221	263	273	296	33.4
39D	217	243	234	277	291	310	33.2
42E	150	173	176	199	215	226	38.8
42D	163	190	189	227	236	254	30.3
42C	172	191	201	238	255	276	30.9
42A	168	188	195	238	253	265	28.0
42B	186	204	215	250	269	278	33.2

GROUP B

No.	Step Bar Section Thickness—in.						
	4[1]		2	1	½	¼	⅛[2]
	Int.	Ext.					
26E	171	200	191	215	228	245	25.6
26C	183	214	206	242	259	277	29.8
26D	182	207	205	242	260	283	31.9
26B	187	217	215	245	265	290	32.1
26A	191	217	218	266	267	293	34.4
27A	167	200	185	207	228	233	27.2
27B	184	212	198	234	246	262	28.4
27C	194	216	210	255	262	274	31.3
27D	201	224	216	255	277	286	35.0
27E	188	230	216	269	277	299	34.1
40A	167	195	188	210	237	233	25.7
40B	188	213	207	232	247	255	26.7
40C	187	214	207	245	263	271	29.4

[1] Brinell hardness of interior and exterior.
[2] Rockwell C.

(*Continued on page 67*)

Table 2 (Continued)

STEP BAR BRINELL HARDNESS

GROUP B (CONTINUED)

No.	Step Bar Section Thickness—in.						
	4[1]		2	1	½	¼	⅛[2]
	Int.	Ext.					
40D	197	222	212	256	276	297	32.6
40E	197	224	216	276	293	303	33.0
41E	154	183	178	212	215	226	38.7
41D	163	196	196	229	238	250	39.0
41C	174	203	209	241	255	276	43.8
41B	179	210	205	254	265	276	47.8
41A	189	215	211	254	269	278	48.3

GROUP C

28A	170	210	204	228	243	269	27.7
28B	171	208	204	233	255	271	28.6
28C	187	196	197	239	269	286	32.3
28D	163	202	193	255	272	286	56.5
28E	170	186	192	236	269	319	61.1
29E	179	200	182	202	240	249	26.5
29D	182	192	192	225	247	249	27.6
29C	180	213	194	239	268	265	30.2
29B	194	200	200	253	272	287	32.9
29A	188	225	203	264	286	298	55.4
43E	148	145	164	189	213	226	22.9
43D	136	149	182	207	231	250	28.3
43C	163	170	195	212	248	250	30.6
43A	168	188	225	269	268	274	34.2
43B	168	171	197	241	269	253	31.6
44A	168	171	183	223	239	274	32.7
44B	182	184	209	239	238	276	29.7
44C	192	175	208	243	268	274	...
44D	171	171	193	246	257	...	...
44E	166	180	197	228	251	276	...

GROUP D

No.	Step Bar Section Thickness—in.						
	4[1]		2	1	½	¼	⅛[2]
	Int.	Ext.					
56A	153	271	272	286	302	320	63.8
56C	256	271	273	302	321	340	66.5
56B	258	272	269	297	311	340	66.0
56D	286	298	285	311	332	400	66.5
56E	286	299	294	321	340	353	67.7
56F	274	288	298	321	340	380	68.5
57A	256	269	261	291	299	320	65.0
57B	269	276	284	318	333	338	64.9
57C	258	274	294	321	336	338	59.5
57E	265	283	288	313	338	342	68.5
57D	279	294	299	323	340	452	68.2
57F	269	285	291	305	323	384	68.6
58F	242	255	254	274	291	338	63.8
58E	269	282	286	319	334	342	66.3

[1] Brinell hardness of interior and exterior.
[2] Rockwell C.

(*Continued on page 68*)

Table 2 (Continued)

STEP BAR BRINELL HARDNESS

GROUP D (CONTINUED)

No.	Step Bar Section Thickness—in. 4[1] Int.	4[1] Ext.	2	1	½	¼	⅛[2]
58D	287	301	300	332	347	378	59.8
58C	274	287	292	321	340	378	65.2
58B	287	289	295	305	338	378	67.0
58A	287	296	296	308	337	378	66.9
59F	215	228	228	251	269	290	59.6
59E	222	241	255	272	302	309	59.5
59D	242	262	273	302	319	325	65.0
59C	259	278	273	302	326	371	66.8
59B	274	291	296	306	333	465	68.2
59A	287	293	299	303	330	452	66.0
			GROUP E				
30A	196	206	212	222	248	257	30.8
30B	217	224	230	255	269	287	33.5
30C	233	248	254	264	293	306	35.4
30D	241	258	258	286	306	330	57.7
30E	240	269	262	288	305	343	55.1
31E	204	229	228	246	255	283	51.8
31D	235	250	253	286	293	303	31.4
31C	244	257	267	293	311	332	48.4
31B	251	270	266	302	327	340	45.1
31A	251	269	270	302	321	354	52.4
32A	218	235	242	267	277	285	51.7
32B	243	261	262	302	305	326	53.7
32C	257	275	275	302	308	346	54.3
32D	253	278	274	314	321	347	46.0
32E	255	271	269	311	318	342	54.2
34E	218	244	240	269	277	...	30.3
34D	243	257	258	302	313	326	42.6
34C	246	269	270	311	321	344	50.5
34B	246	254	260	305	319	339	45.3
34A	249	274	261	305	321	352	56.4
36A	207	227	217	246	264	284	46.5
36B	227	248	243	278	297	297	49.6
36C	242	263	258	287	311	326	51.4
36D	245	268	263	305	322	346	57.2
36E	255	270	267	302	330	415	55.5
37E	208	228	221	256	269	286	47.7
37A	228	248	241	286	294	307	32.7
37D	232	262	257	304	311	345	35.2
37B	242	270	269	309	319	343	35.9
37C	240	265	264	319	321	345	...
			GROUP F				
33A	207	225	231	254	267	271	28.6
33B	221	236	236	269	286	290	30.2
33C	227	237	250	280	302	311	31.5
33D	239	246	255	299	311	337	...

[1] Brinell hardness of interior and exterior.
[2] Rockwell C.

(*Continued on page 69*)

Table 2 (Continued)

STEP BAR BRINELL HARDNESS

(GROUP F (CONTINUED))

No.	Step Bar Section Thickness—in.						
	4[1]		2	1	½	¼	⅛[2]
	Int.	Ext.					
33E	225	243	249	286	308	342	56.8
35E	226	237	240	256	283	289	29.4
35D	243	263	274	302	313	310	33.1
35C	241	263	265	305	304	319	34.9
35B	230	254	257	286	311	...	...
35A	231	257	265	296	305	329	55.6
60A	208	225	236	251	269	277	53.1
60B	230	250	249	286	299	317	51.7
60C	238	258	262	299	309	324	52.3
60D	251	274	263	301	321	342	54.0
60E	236	267	260	302	321	342	55.6
60F	236	260	261	311	324	344	56.1
61F	208	228	225	249	263	280	50.4
61E	214	229	230	255	264	280	49.6
61D	229	254	255	286	294	338	52.5
61C	243	265	258	293	315	348	54.4
61A	243	266	258	300	321	378	67.2
61B	240	260	246	296	313	351	55.4

[1] Brinell hardness of interior and exterior.
[2] Rockwell C.

up to 3.0 per cent increases the Brinell about 18 points, but if the silicon is about 2.25 per cent, the increase is about 14 points. This relationship is about the same for both the dry sand and green sand bars. At the beginning of this research project, it was thought that copper might offset the adverse effects of high silicon. The hardness data show that copper does not markedly harden the high-silicon base-iron represented by group *C*. It will be observed later that copper also does not improve the other properties of this high-silicon iron.

26. The relation of copper content to the Brinell hardness of the 4-in. sections of the step-bar is given in Table 2. The 4-in. sections were cut in half through the center and the Brinell hardness was obtained at each 1/4-in. interval from the center to the outside. The same relationships observed previously concerning the 1.2-in. diameter bar apply also to the hardness of the 4-in. sections, the principal difference being that the increase in Brinell hardness for each per cent of copper is 2 or 3 points less than that for the smaller 1.2-in. sections—the hardness of the 4-in. section being taken one inch from the center.

27. The increase in Brinell hardness with increasing copper content noted in previous paragraphs, and the influence of section size, silicon, and carbon contents on the amount of this increase,

are further substantiated by the Brinell hardness of the 2, 1, 1/2, and 1/4-in. sections of the step-bar cast in green sand. The hardnesses of these sections are given in Table 2 and are not graphically represented.

28. The extensive determination of the Brinell hardness in sections of various sizes as well as the investigation of the hardness from the center to the exterior of the 4-in. and 2-in. sections, has made it possible to determine the influence of section size in copper-bearing gray iron. The differences in hardness of the 4-in. and 1/2-in. sections were plotted against copper content. These curves, not presented in this paper, indicate that copper slightly increases this difference in hardness of the large and small sections (as much as 5 to 10 points Brinell at 3.0 per cent copper in the low-silicon iron, groups *A* and *E*, and about 10 to 15 points Brinell in the higher silicon irons).

29. There is always some increase in hardness of large sections from the center to the exterior. When the difference in hardness of the interior and exterior of the 4-in. sections is plotted against the copper content, it is found that copper neither increases nor decreases this variation in any of the six base-irons. Thus, copper does not materially affect the uniformity of hardness within a given section.

Transverse Strength

30. The relation of breaking load to copper content of the 1.2-in. diameter bars cast in green sand is shown in Fig. 3D. The breaking loads recorded in the tables are values corrected to 1.20-in. diameter for the span of 18 inches. The green sand bars were broken in the same position in which they were cast. It is evident that copper has a slightly adverse effect upon the breaking load of all six types of base-iron; this decrease is slightly greater in the green sand bars, amounting to 100 to 200 lb. at 3.0 per cent copper. The breaking load of the higher-silicon and lower-carbon dry sand bars is not adversely affected by the copper up to 3.0 per cent (groups *B, D, E,* and *F*).

31. The increase in hardness caused by the copper is reflected in lower deflection values for both dry sand and green sand bars in all six groups, though the highest strength iron, group *D,* is not affected adversely to any noticeable extent. These values are given in Table 1.

32. The copper does not improve the results for irons of

the highest silicon content represented by group *C*. These heats gave inconsistent results and are uniformly inferior.

Tensile and Compressive Strength

33. The effect of copper upon the tensile strengths and upon the corresponding compressive strengths of the green sand and dry sand bars are illustrated in Figs. 3A and 3B respectively. The increase in tensile strength is very marked in some of the compositions, being greatest in the green sand bars of low silicon content. The tensile strengths of the high-silicon irons are not improved by the copper addition.

34. As shown in Fig. 3B, the compressive strengths of all except the very high silicon irons are very markedly improved. The maximum increase in compressive strength occurs in the low-silicon iron.

Total Shrinkage

35. Contrary to many published reports, the total shrinkage, as definitely shown by a great many determinations, increases slightly with increasing copper for all six groups of base-iron. This increase in total shrinkage is not large, however, being about 0.007 in. per ft. for each per cent of copper up to 3.0 per cent.

Influence of Copper on Chill

36. Scores of determinations clearly show that copper has no influence upon chill when silicon is higher than 2.0 per cent, as in groups *B*, *C*, and *F*. There is a very slight tendency to increase chill in these irons when the copper exceeds 3.0 per cent. On the chill blocks used in this investigation, this slight increase is not more than 1/16 in. for each per cent of copper above 3.0 per cent.

37. When the silicon is about 1.75 per cent with low carbon, as in group *D*, each per cent of copper up to 3.0 per cent reduces the chill about 1/16-in. on the chill block 4-in. long, 2-in. high, and 1-in. thick, cast on edge. Copper above 3.0 per cent in this iron has a tendency to increase the chill slightly—about 1/16-in. for each per cent of copper.

38. When the silicon is 1.25 to 1.50 per cent, as in groups *A* and *E*, copper up to 4.0 per cent reduces chill markedly, this decrease being about 1/8-in. for each per cent of copper up to

3.0 per cent. In group *E*, when the copper exceeds 4.0 per cent, there is a slight increase in chill. Thus the influence of copper on chill is determined principally by the silicon content, a fact which explains many of the contradictions in the published data on this subject.

The Tendency of Copper to Prevent Chill in Small Sections

39. This effect of copper is closely related to its influence upon chill produced upon the chill block and, as might be anticipated, the effects are parallel.

40. The step-bar described previously clearly shows the effect of copper upon the tendency of the iron to chill in small sections. This step-bar contains 6 sections, each 4-in. long and 1/8, 1/4, 1/2, 1, 2, and 4-in. thick. The first 5 sections are 2-in. wide, and the last is 4-in. wide. The small sections tend to chill, the tendency to chill being manifested in the greater distance that the white iron extends up the bar toward the heavier sections. When referring to the amount of chill, the length of section totally white, measured from the tip of the smallest end, will be given.

41. Low-silicon iron containing moderately high carbon, as represented by group *A*, has less tendency to chill in small sections when copper is added, this decrease being from 3 in. of white iron at 0.0 per cent copper to 1.5-in. at 3.0 per cent. With similar silicon content but lower carbon, as represented by group *E*, the length of white iron is reduced from 3.7 to 2 in. for the same copper range. Above 3.0 per cent copper in this latter group, the length of chill is increased again, until at 4.5 per cent copper, it is about the same as at 0.0 per cent.

42. When the silicon is near 2.0 per cent, as in groups *B*, *D*, and *F*, the copper does not affect the length of chill up to about 3.0 per cent copper, but above this amount, it tends to increase the chill slightly in the small sections.

43. When the silicon is very high, as in group *C*, the copper has no influence up to 1.0 per cent, but above this amount it increases the chill markedly, the chill being nothing at 0.0 per cent copper and 1.25 in. of white iron at 3.0 per cent copper.

44. The graphitization in small sections is an important factor, since it eliminates the hard spots in the smaller sections of gray iron castings. The influence of copper upon this graphitization is intimately related to silicon content as already shown.

Since chill in small sections is naturally most pronounced in irons of low silicon content, the copper has a marked beneficial effect upon the graphitization of the cementite in the light sections of such iron.

45. The Ford Motor Company, in private communication, offers corroborative information as follows: In chilled and gray iron "our percentages of copper vary somewhat but for the most part run from 0.75 to 1.00 per cent. The copper helps the fluidity of gray iron considerably and acts as a graphitizer. It hardens and tightens up the matrix to such an extent that the so-called "sponginess" in gray iron is lessened. In castings where there are a number of light and somewhat heavier sections, copper aids greatly in helping (preventing) these light sections from chilling and holds a fine structure in the heavy ones * * * it thus acts as a stabilizer * * *."

46. The tendency of the combined carbon to increase slightly with increasing copper, as given in Table 1, cannot be considered as evidence that copper retards graphitization of free cementite. It is well known that the eutectoid cementite graphitizes much less readily than proeutectoid or eutectic cementite. Rather, the increase in combined carbon is support of the contention of E. Reed[4] that copper increases the carbon content of the eutectoid.

Machinability

47. The best measure of machinability is a production test, since machinability is dependent upon many factors. Among them the most important is the presence of free cementite. Such hard particles are very detrimental. Therefore, increased hardness may not mean increased machining difficulties unless the increased hardness is due to free carbides. Since it has been observed that copper causes graphitization in low-silicon iron, it is reasonable to expect that copper would increase the machinability of small sections in such iron, though production tests have not been run for the purpose of substantiating this belief.

Red Shortness

48. Because the occurrence of red shortness in copper-bearing gray cast iron would be a serious limitation and because increased red shortness has been attributed to copper, this characteristic has been very carefully studied. The clamp shaped test

[4] Reed, E., Trans, A.S.S.T., vol. 20, no. 2, pp. 115-175 (1932).

bar, illustrated in Fig. 2D, was cast with each set of test bars, the length of the arms of the clamp being 2-1/4, 3-1/4, or 4-in. The shorter the arms, the greater the strain at the corners and the greater the likelihood of failure in the mold. The steel bar was always cast in contact with the arms of the clamp, so that shrinkage in the distance between the arms of the clamp was completely prevented. It was found that the copper-bearing iron never failed when the length of the arms was 4 in. When the length was reduced to 2-1/4 or 3-1/4 in., the copper-bearing iron failed no more frequently than the plain iron. This absence of red shortness in the copper-bearing iron is in conformity with the fact that copper, in the ordinary amounts used in gray iron, does not form a part of a network structure of any kind, the copper being in solution in the austenite at high temperatures.

Amenability to Precipitation Hardening

49. A consideration of the constitution diagram of the iron-copper-carbon alloys indicates a marked decrease in solubility of copper in the solid state, from about 5.0 per cent (depending upon the carbon content) at high temperatures to a very few tenths of one per cent at room temperature. The decrease in solid solubility is ideal for precipitation hardening. The temperature used for precipitation was 500 deg. C. (932 deg. F.) since this temperature was found by Cyril S. Smith[5] to be suitable for the precipitation hardening of copper-bearing malleable cast iron.

50. To investigate the amenability of the copper-bearing gray cast iron to precipitation hardening, the 5/8-in. bars used in the red shortness test and the 4-in. sections of the step-bar of the following heat were selected for testing:

	Analysis			Brinell	
				Original	Step-Bar
No.	Si., per cent	Mn., per cent	Cu., per cent	5/8-in. Section	4-in. Section
61A	2.14	0.66	3.76	312	248
61C	2.25	0.65	2.76	308	246
61D	2.22	0.60	1.91	305	239
61F	2.17	0.67	0.48	265	213

51. After heating for 1, 2, 4, and 6 hours at 500 deg. C. (932 deg. F.), none of the 4-in. sections could be increased in hardness, this property remaining practically unchanged. The

[5] Smith, C. S., TRANS. A.I.M.E. vol. 116, pp. 363-385 (1935).

small sections of 61*A* and 61*C* were increased 13 points Brinell at the end of 2 hours, while the other two samples, 61*D* and 61*F*, were practically unchanged. It is reasonable to suppose, therefore, that copper-bearing gray iron is not amenable to precipitation hardening, except when the section is small and the copper content above 3.0 per cent. The small section apparently is necessary because of the more rapid cooling which maintains the copper in supersaturated solution. It is thus improbable that the precipitation hardening of plain copper gray iron will ever be of much importance. A normalizing treatment at a temperature just under the $Ac_{3,2,1}$ point was not tried prior to an aging treatment. Because of complications, such a treatment would cause other changes in addition to its effect on the condition of the copper.

Microstructure and Fracture

52. All of the six sections of the step-bars from heats No. 27 and 38 were examined to determine the effect of copper upon the size, shape, and distribution of graphite flakes. In the relatively high-carbon, high-silicon heat No. 27 (2.5 per cent silicon), there was a slight, though not marked, progressive refinement of the graphite flakes in all of the sections which were gray. However, when the silicon is lower (1.35 per cent), as in heat No. 38, the copper produces a marked and progressive refinement of the graphite flakes in all of the sections which are gray.[6]

53. The investigation of the unetched surfaces of these same irons, Nos. 56*A*, 56*B*, 56*E*, and 56*F*, reveals that all of them contain small particles of copper, usually euhedral crystals. These crystals are very small, about 0.001 mm., and frequently occur near a sulphide particle. The quantity of these copper crystals does not appear to be markedly affected by high copper contents since the copper present in these tiny crystals is about the same amount, probably not over 0.2 per cent copper, in heat No. 56 through the range of copper content in this heat. Even after slow cooling from 750°C. (1382° F.), the quantity of the copper precipitated did not increase. It is quite probable that the occurrence of these small copper crystals is intimately connected with the sulphide. K. L. Meisner[7] found that, in the absence of manganese, the sulphur would be present as Cu_2S, but in the presence of manganese it would occur as MnS. If the sulphur occurs as

[6] Photomicrographs available in manuscript, loc. cit Note 1.
[7] Meisner, K. L., Metal und Erz, vol. 18, pp. 358-359 (1921).

Cu_2S, one part of sulphur would cause the formation of about twice as much sulphide as compared with manganese sulphide. It is quite possible that, when sulphur occurs with manganese, iron, and copper in the proportion of copper-bearing iron, the sulphur is present as Cu_2S or as complex sulphide. This statement is based on the following observations: (1) The light color of the sulphide; (2) well formed euhedral crystals instead of the rounded ones typical of MnS; (3) the large quantity of sulphide produced by a small sulphur content.

54. The copper produces a finer fracture than corresponding plain iron. This refinement of the fracture by the copper is most pronounced in the lower silicon irons, particularly when the low silicon is accompanied by low carbon content.

Permanent Growth and Resistance to Scaling

55. The dry sand gates of heat No. 30 were machined to cylinders of ⅝-in. diameter and 3-in. long, producing 6 specimens for each of the 5 compositions of this heat. These specimens contained 1.5 per cent silicon and 3.15 per cent total carbon, while the copper contents were 0.20, 1.25, 2.3, 3.55, and 5.08 per cent. One set of these specimens was heated to 750° C. (1382° F.) for one hour and furnace cooled. A second set was heated twice to 750° C. (1382° F.) and furnace cooled, a third set three times, etc., the sixth set being reheated six times. The increase in length and the increase in weight of each specimen were carefully determined, thus giving accurate data on permanent growth and scaling at 750° C. (1382° F.) in the fairly oxidizing conditions existing in the closed muffle of the furnace.

56. The data obtained clearly showed that, in this iron investigated, the copper had no effect upon the amount of scale found nor upon its adherence to the iron.

57. The following data show the increase in inches for the 0.2 per cent and 3.55 per cent copper specimens after the first, third, and sixth heatings to 750° C. (1382° F.):

No. of Heatings to 750° C. (1382° F.)	Increase in length—in.	
	0.2% Cu.	3.55% Cu.
1	.0125	.0165
3	.0185	.0225
6	.0195	.0260

58. These data are representative of the increase in perma-

nent growth with increasing copper, the rate of this increase being the greatest up to 2 per cent copper.

59. Data on permanent growth obtained by R. J. Marcotte[8] using a Leitz dilatometer also show that the iron of heat No. 27 has a greater permanent growth with increasing copper, after reheating 4 times to 875° C. (1670° F.), the increased growth being of the same order of magnitude as that represented by the previous data.

Coefficient of Thermal Expansion

60. Coefficients of thermal expansion, determined by Mr. Marcotte on heat No. 27, show that the coefficient of thermal expansion is not affected by the copper content up to about 500° C. (932° F.), but that when this temperature is reached the coefficient increases slightly. The following data show the value of the coefficient of thermal expansion per ° C.

	Analysis*—Per Cent			Coeff. of Thermal Expansion per °C × 10^6		
No.	Si.	T.C.	Cu.	25-200° C.	25-400° C.	25-600° C.
27A	2.49	3.21	0.16	10.55	12.47	13.33
27B	2.55	3.16	0.83	10.67	12.9	13.64
27C	2.51	3.15	1.54	10.61	12.79	13.71
27D	2.51	3.16	2.46	10.39	12.90	13.98
27E	2.47	3.11	3.36	10.39	12.90	14.06

* See Table 1 for complete analysis.

Thermal Critical Points

61. The temperatures of the thermal critical points, determined simultaneously with the coefficient of thermal expansion, show that the copper lowers both the $Ac_{3,2,1}$ and $Ar_{3,2,1}$ in the cast iron of heat No. 27. The $Ac_{3,2,1}$ is lowered uniformly 6° C. (10.8° F.) for each per cent copper up to at least 2.5 per cent.

62. The $Ar_{3,2,1}$ is lowered uniformly 13° C. (23.4° F.) for each per cent of copper up to at least 2.5 per cent. The heating rate through the critical temperature was about 12.5° C. (22.5° F.) per minute and the cooling rate about 11° C. (19.8° F.) per minute.

Copper-Manganese Cast Iron

63. So far as the authors are aware, the use of high manganese with copper (more than 0.8 per cent manganese being con-

[8] Department of Physical Metallurgy, Michigan College of Mining and Technology.

sidered high) has never received attention. The copper-manganese combination as alloying materials in gray iron offers the advantage of cheapness as compared with other alloying elements. This factor, together with the improved properties attained by the use of these metals as alloying materials, should stimulate their development in the gray iron industry.

64. As was stated previously, an attempt was made to add the manganese in the cupola as a high-manganese pig, producing a base-iron containing 2.0 to 3.0 per cent manganese to which the copper might be added. The straight high-manganese gray iron without copper has not been fully studied, and the effects of high manganese alone are rather obscure. However, the addition of high-manganese pig to the charge produced an iron containing 1.5 to 2.5 per cent manganese which had a slight but definite tendency to form white iron in small sections, and to increase chill even if the silicon was maintained above 1.75 per cent to permit machining. Such a gray iron, though the heat was repeated several times, was invariably unsound and weak and was little improved by the copper additions. However, this method has been used with success in chilled iron—which phase of the cast iron program is not reported in this paper. It is interesting to note that the effect of copper upon the decomposition of free cementite is about the same in this high-silicon, high-manganese iron as in the high-silicon iron of normal manganese content,—*i. e.*, the copper retards graphitization slightly.

65. After several unsuccessful attempts to add manganese in the cupola in the form of a high-manganese pig with a view to producing a high-manganese gray iron, a new method was tried. This consisted of melting copper and standard ferromanganese together, forming a copper-manganese alloy which has a melting point much under that of pure copper. The alloy, formed by melting the copper and standard ferromanganese (80 per cent manganese) in a ratio of 5 to 3, was added molten to the forehearth or ladle in precisely the same manner as the molten copper was added to form the plain copper irons. Such a copper-manganese alloy would contain about 63 per cent copper, 32 per cent manganese, and 5 per cent iron. No difficulty was experienced in producing a sound iron by this method of alloy addition. The alloy could be added solid in the form of shot when the cupola was tapped, because it melts readily and dissolves in the melt, forming a homogeneous alloy cast iron.

66. The same base-irons as were used for the plain copper gray iron were made, each being run in quadruplicate, two with the alloy additions increasing with the slightly decreasing casting temperature, and two with the alloy additions decreasing with the slightly decreasing casting temperature. The method of melting and testing the iron was the same as that described previously for the plain copper irons. The copper-manganese alloy was added molten, just as the copper was first melted before being added to the plain copper gray irons.

67. All of the six base-irons, excepting *C* of paragraph 6, have been run to date, each in quadruplicate, all unsatisfactory heats having been repeated. Thus 20 or more heats have been cast, each having 5 or 6 copper-manganese alloy additions with a corresponding number of sets of test bars. Beside these 126 different compositions of copper-manganese gray iron, six heats of a high-manganese base-iron were run, but as noted previously, they were unsound and were, therefore, not fully tested. They gave valuable information, however, regarding the effect of copper on the hardness and graphite formation in such high manganese iron.

68. Not all of the tensile and compressive strength data are available on group *D*, and consequently Table 3, which lists the mechanical properties of the green sand and dry sand 1.2-in. diameter bars, is not complete. The hardnesses of the step bars are given in Table 4, while the complete analyses are given in Table 3 only. Each heat is arranged with increasing copper and manganese contents, the letters *A*, *B*, etc. indicating the progressive order of casting.

RESULTS OF TESTING COPPER-MANGANESE GRAY IRON

69. The mechanical properties of the copper-manganese irons are listed in Table 3, each heat being separated from the next, and the iron of each heat being arranged in an order of increasing copper and manganese contents. Theoretically, the copper and manganese should increase in the ratio of 2 to 1, since this is the ratio of copper to manganese in the alloy. However, there is a marked tendency for a preferential solution of the manganese in the alloy by the iron, leaving the copper-rich liquid at the bottom or to be dissolved later. It is thus possible to have varying proportions of copper and manganese. Because of this factor and the initial content of 0.5 to 0.7 per cent manganese,

Table 3

ANALYSES AND PROPERTIES OF GREEN AND DRY SAND ARBITRATION BARS

No.	Analysis—Per Cent: Cu.	Si.	Mn.	P.	S.	C.	Step Bar: G.C.	C.C.	Brinell Hardness: D[1]	G[2]	Tensile Strength lb. per sq. in.: D[1]	G[2]	Comp. Strength, lb. per sq. in.: D[1]	G[2]	Transverse Test—Load—lb.: D[1]	G[2]	Deflection—in.: D[1]	G[2]	Mod. of Rupture lb. per sq. in.: D[1]	G[2]
GROUP A																				
51A	0.48	1.37	0.25	0.27	0.10	3.39	2.50	0.89	241	241	34,686	35,840	135,400	135,333	2415	2215	0.199	0.188	64,100	58,800
51B	0.98	1.32	0.51	0.28	0.10	3.33	2.40	0.93	241	237	35,700	36,640	128,066	129,966	2300	2337	0.207	0.193	61,200	61,900
51C	1.35	1.34	0.70	0.26	0.09	3.37	2.40	0.97	255	252	29,053	36,456	131,366	133,600	2410	2193	0.211	0.176	64,000	58,200
51D	2.14	1.34	1.04	0.26	0.08	3.32	2.44	0.88	257	256	36,846	41,230	137,400	140,500	2130	2116	0.188	0.166	56,500	55,600
51E	3.25	1.29	2.38	0.27	0.08	3.24	2.34	0.90	299	293	29,030	36,223	154,750	154,900	....	1690	.....	0.140	.....	44,700
52A	0.21	1.10	0.64	0.15	0.10	3.56	2.72	0.84	207	205	33,840	32,836	110,050	116,700	2543	2356	0.278	0.301	68,100	62,600
52B	0.33	1.12	0.62	0.15	0.09	3.46	2.70	0.76	208	207	32,680	32,993	117,580	116,933	2520	2406	0.306	0.267	66,700	63,800
52C	0.67	1.07	0.87	0.15	0.10	3.47	2.63	0.84	219	217	36,300	35,893	124,703	120,066	2570	2435	0.273	0.238	68,200	64,200
52D	1.06	1.07	1.15	0.16	0.09	3.27	2.58	0.69	238	239	37,550	38,900	128,233	127,106	2540	2550	0.242	0.239	66,500	68,200
52E	2.25	1.01	1.34	0.15	0.09	3.58	2.56	1.02	269	269	41,295	44,610	138,566	143,433	2703	2470	0.232	0.202	71,300	65,400
53E	0.16	1.38	0.64	0.26	0.08	3.25	2.73	0.70	209	210	33,206	34,206	120,866	122,866	2463	2263	0.268	0.177	65,300	60,200
53D	0.64	1.43	0.80	0.26	0.08	3.33	2.70	0.70	227	228	37,066	37,366	127,100	132,300	2353	2592	0.231	0.230	62,400	68,700
53C	0.84	1.43	0.90	0.26	0.08	3.44	2.63	0.73	229	230	38,146	38,860	130,300	132,200	2385	2450	0.244	0.218	63,000	64,800
53A	1.54	1.36	1.34	0.23	0.08	3.34	2.60	0.83	256	255	42,776	42,300	134,400	139,566	2483	2418	0.233	0.195	66,100	64,100
53B	1.49	1.41	1.28	0.25	0.08	3.32	2.57	0.84	253	256	41,012	42,896	130,733	139,900	2398	2442	0.226	0.190	63,200	64,700
54E	0.40	1.32	0.57	0.27	0.09	3.37	....	....	217	217	33,233	34,966	120,533	121,546	2333	2303	0.246	0.211	62,100	60,300
54A	0.84	1.29	1.13	0.25	0.08	3.24	2.52	0.72	255	255	40,860	41,656	134,533	134,533	2390	2323	0.207	0.197	63,300	61,300
54D	0.91	1.30	0.91	0.24	0.08	3.29	2.64	0.65	238	246	37,066	38,866	128,100	129,100	2353	2277	0.196	0.195	63,400	60,500
54C	1.21	1.33	1.01	0.25	0.08	3.38	2.47	0.91	250	255	39,651	39,990	131,993	135,566	2365	2345	0.201	0.194	58,000	62,200
54B	1.58	1.29	1.18	0.25	0.08	3.35	2.51	0.84	257	262	41,916	42,386	136,233	141,166	2283	2373	0.199	0.185	60,600	63,000
55A	0.25	1.26	0.66	0.21	0.08	3.24	2.58	0.66	...	206	.....	32,800	.....	112,350	....	2290	.....	0.242	.....	60,900
55B	0.57	1.33	0.77	0.23	0.08	3.55	2.80	0.75	218	218	36,600	35,933	123,133	122,600	2395	2287	0.235	0.212	63,600	60,700
55C	0.93	1.34	0.93	0.24	0.07	3.43	2.83	0.60	...	228	.....	37,333	.....	124,215	....	2320	.....	0.212	.....	61,500
55D	1.18	1.35	1.36	0.23	0.07	3.29	2.64	0.65	243	245	37,600	39,263	130,033	132,600	....	2465	.....	0.208	.....	62,800
55E	1.68	1.34	1.72	0.23	0.06	3.53	2.66	0.87	...	269	.....	43,850	.....	141,566	....	....	.....	.....	.....	.....
55F	1.75	1.37	1.68	0.23	0.06	3.36	2.49	0.87	274	269	.....	37,766	142,853	140,233	....	....	.....	.....	.....	.....
76A	0.08	1.38	0.35	0.19	0.09	3.43	2.42	1.01	197	198	33,700	33,130	118,600	116,366	2381	2223	0.296	0.245	63,200	58,900
76B	0.42	1.20	0.53	0.19	0.09	3.48	2.81	0.67	215	216	35,630	35,970	120,933	124,133	2405	2264	0.248	0.240	62,400	59,000
76C	0.82	1.24	0.75	0.18	0.10	3.39	2.52	0.87	218	226	37,550	37,300	123,183	124,766	2485	2460	0.247	0.234	65,900	62,900
76D	1.28	1.19	0.99	0.18	0.09	3.44	2.65	0.79	238	248	36,510	40,220	132,133	141,500	2469	2461	0.219	0.215	65,000	65,300
76E	2.50	1.20	1.33	0.18	0.08	3.44	2.68	0.76	264	272	34,920	36,520	144,200	149,633	2320	2180	0.206	0.175	61,600	59,600
GROUP B																				
47A	0.19	2.35	0.69	0.25	0.10	3.32	2.76	0.63	219	217	32,766	35,026	120,516	122,956	2150	2323	0.220	0.257	57,000	61,600
47B	0.46	2.32	0.84	0.25	0.08	3.24	2.60	0.60	288	225	35,866	35,943	126,536	124,000	2340	2253	0.238	0.225	62,100	59,900
47C	0.94	2.28	0.88	0.25	0.08	3.23	2.62	0.53	240	241	37,673	37,286	136,733	127,500	2305	2427	0.220	0.220	61,200	64,400
47D	1.43	2.29	1.34	0.25	0.07	3.20	2.60	0.55	255	255	37,106	38,793	134,033	136,966	2273	2300	0.197	0.205	60,300	61,000
47E	3.03	2.20	2.01	0.24	0.07	3.18	2.54	0.58	286	286	40,030	39,096	146,000	152,733	2530	2533	0.212	0.180	67,100	61,000
48A	0.20	3.06	0.51	0.26	0.08	3.22	2.63	0.59	195	192	25,513	25,313	97,666	97,450	1980	1923	0.213	0.220	52,500	50,900
48B	0.48	3.06	0.66	0.27	0.09	3.22	2.82	0.40	200	203	27,846	26,950	106,266	102,766	1870	1970	0.220	0.207	49,500	52,200
48C	1.06	2.94	1.00	0.27	0.10	3.19	2.81	0.38	224	218	30,500	29,546	111,400	108,966	1940	1915	0.202	0.180	51,400	50,700
48D	1.39	3.05	1.42	0.26	0.08	3.18	2.64	0.54	242	241	33,133	31,906	120,700	120,100	2015	2087	0.172	0.191	53,400	55,300
48E	2.85	2.83	2.47	0.25	0.02	3.17	2.46	0.71	286	294	31,966	33,820	141,900	142,933	2123	....	0.184	.....	56,300	.....

49E	0.40	2.72	0.70	0.23	0.10	3.20	2.60	0.61	217	217	32,246	34,540	121,050	120,266	2210	2350	0.192	0.218	58,600	62,400
49D	1.25	2.73	1.00	0.23	0.09	3.21	2.62	0.62	241	230	35,973	37,280	132,400	127,933	2156	2223	0.186	0.202	57,300	59,100
49C	1.48	2.71	1.12	0.22	0.09	3.20	2.62	0.62	250	254	37,466	37,426	133,333	130,000	2270	2433	0.198	0.207	56,800	64,800
49A	2.28	2.65	1.53	0.22	0.08	3.12	2.46	0.66	272	268	35,466	38,380	139,200	134,700	2270	2277	0.196	0.199	60,200	60,400
49B	2.24	2.65	1.35	0.22	0.08	3.13	2.60	0.56	260	257	35,600	35,380	133,000	136,266	2173	2240	0.161	0.196	57,500	59,500
50E	0.14	3.10	0.60	0.24	0.10	2.80	2.30	0.62	...	215	.....	32,313	.....	117,500	....	2290	.....	0.229	.....	60,700
50D	0.68	3.10	0.81	0.24	0.11	2.91	2.35	0.65	228	229	34,300	36,306	123,000	125,353	2345	2133	0.228	0.195	56,600	56,600
50C	0.88	3.15	0.82	0.25	0.10	2.92	2.38	0.74	236	235	35,040	34,866	123,566	123,773	2113	2280	0.208	0.198	56,000	60,500
50A	1.04	3.15	1.16	0.25	0.10	3.08	2.31	0.75	237	245	37,960	34,353	131,266	126,300	2130	2283	0.199	0.198	56,600	60,600
50B	1.69	2.82	1.14	0.25	0.10	3.07	2.40	0.72	249	247	37,680	33,653	132,500	131,166	2177	2237	0.200	0.192	57,700	59,300
GROUP D																				
79A	0.10	2.30	0.69	0.02	0.13	2.97	2.38	0.59	248	240	46,470	.....	145,850	.....	2770	2702	0.267	0.230	73,400	71,700
79B	0.60	2.28	1.30	0.03	0.12	3.01	2.32	0.69	256	269	51,200	51,970	156,900	152,660	3100	2903	0.272	0.229	81,800	77,100
79C	1.00	2.24	1.06	0.03	0.13	2.83	2.22	0.61	289	280	56,900	.....	162,760	.....	3283	2886	0.276	0.213	87,200	76,600
79E	1.92	1.50	1.00	0.02	0.12	2.85	2.09	0.76	280	281	54,200	57,560	167,850	167,900	3198	2829	0.254	0.195	84,800	75,000
79D	2.06	2.06	1.48	0.03	0.13	2.85	2.14	0.71	294	302	59,700	58,500	173,000	175,700	3192	3053	0.249	0.210	84,700	81,100
79F	3.28	1.50	1.57	0.03	0.11	2.87	2.10	0.77	302	323	48,800	.....	172,850	.....	3250	2807	0.245	0.181	86,200	74,500
80A	0.11	3.37	1.11	0.03	0.11	2.88	2.42	0.46	240	240	.....	.....	.....	.....	2468	3014	0.240	0.216	61,400	62,300
80C	0.56	1.26	0.67	0.02	0.13	3.03	2.41	0.62	...	252	.....	.....	.....	.....	....	2851	.....	0.220	.....	73,900
80B	0.20	3.33	1.09	0.04	0.11	2.90	2.50	0.40	241	239	.....	.....	.....	.....	2650	3018	0.276	0.224	70,200	65,000
80D	0.79	1.28	0.81	0.02	0.14	3.15	2.34	0.81	255	258	.....	.....	.....	.....	2808	2811	0.255	0.216	74,500	74,600
80E	1.93	0.93	0.96	0.02	0.11	3.03	2.34	0.69	273	284	.....	.....	.....	.....	3133	2725	0.255	0.189	84,800	72,500
80F	2.52	0.85	1.23	0.02	0.11	3.01	2.12	0.89	300	313	.....	.....	.....	.....	3429	2708	0.267	0.174	90,900	71,800
81F	0.15	1.17	0.47	0.01	0.11	3.11	2.15	0.96	250	244	.....	.....	.....	.....	3275	3380	0.281	0.243	86,400	89,700
81E	1.06	1.15	0.84	0.02	0.11	2.97	2.27	0.70	265	264	.....	.....	.....	.....	2871	2734	0.241	0.215	76,100	72,400
81D	1.32	2.04	1.04	0.03	0.11	3.04	2.18	0.86	280	283	.....	.....	.....	.....	3065	2917	0.245	0.220	81,400	77,400
81B	1.74	1.98	1.26	0.02	0.11	2.88	....	....	284	296	.....	.....	.....	.....	2532	2733	0.226	0.200	67,100	72,600
81C	2.39	1.92	1.33	0.02	0.11	2.98	2.16	0.82	308	305	.....	.....	.....	.....	2906	3017	0.230	0.222	77,100	80,100
81A	2.32	1.97	1.50	0.02	0.11	2.90	2.13	0.77	307	315	.....	.....	.....	.....	2682	2658	0.220	0.186	71,200	70,600
82F	0.16	1.63	0.48	0.01	0.11	3.10	2.50	0.60	237	231	.....	.....	.....	.....	2465	2626	0.231	0.210	65,300	69,300
82E	0.50	1.61	0.62	0.02	0.13	3.16	2.44	0.72	247	248	.....	.....	.....	.....	2691	2644	0.241	0.212	71,400	70,700
82D	0.98	1.59	0.81	0.02	0.13	3.17	2.39	0.78	261	258	.....	.....	.....	.....	2795	2770	0.249	0.201	74,200	73,500
82C	2.20	1.52	1.10	0.03	0.13	3.08	2.18	0.90	286	293	.....	.....	.....	.....	3100	3230	0.241	0.233	82,300	85,700
82B	....	....	....	....	....	....	....	....	....	....	.....	.....	.....	.....	....	....	.....	.....	.....	.....
82A	2.83	1.77	1.34	0.02	0.12	2.92	2.03	0.89	325	327	.....	.....	.....	.....	3000	2990	0.212	0.185	79,500	79,300
GROUP E																				
73F	0.21	1.50	0.70	0.17	0.10	3.14	2.51	0.63	228	236	38,300	36,550	131,700	128,250	2493	2477	0.266	0.236	66,600	66,600
73E	0.35	1.45	0.77	0.17	0.10	3.10	2.39	0.70	233	247	40,775	41,100	136,630	138,400	2707	2513	0.285	0.225	71,800	66,400
73C	0.95	1.49	0.88	0.17	0.10	3.17	2.35	0.82	249	268	42,350	41,026	138,200	140,300	2457	2285	0.232	0.196	64,100	60,700
73A	1.14	1.56	0.89	0.17	0.09	3.05	2.38	0.67	254	264	39,175	40,616	139,300	142,300	2637	2400	0.243	0.209	70,000	63,600
73B	1.30	1.43	0.94	0.17	0.09	3.15	2.30	0.85	255	268	38,700	40,988	139,100	144,500	2293	2330	0.218	0.200	61,700	61,800
73D	1.37	1.48	0.97	0.17	0.09	3.15	2.30	0.85	271	268	37,466	40,677	141,620	139,700	2253	2400	0.190	0.228	59,900	63,600
74A	0.17	1.44	0.74	0.17	0.10	3.07	2.48	0.59	228	236	41,068	42,980	135,350	141,600	2717	2747	0.281	0.234	74,100	72,900
74B	0.35	1.41	0.87	0.17	0.11	3.06	2.43	0.63	242	245	44,250	45,635	135,950	141,600	2705	2708	0.259	0.220	71,800	71,100
74C	0.69	1.44	1.03	0.19	0.11	3.04	2.41	0.63	255	262	47,660	45,210	145,550	149,200	2963	2950	0.264	0.230	78,600	78,200
74D	1.23	1.29	1.27	0.18	0.16	3.04	2.27	0.77	280	278	46,620	44,300	150,300	149,160	2385	2617	0.207	0.185	.....	69,300
74E	1.92	1.35	1.42	0.18	0.08	3.11	2.26	0.85	278	286	.....	41,362	148,600	156,860	2230	2445	0.180	0.175	.....	65,700
74F	2.56	1.38	1.87	0.18	0.09	3.06	2.21	0.85	296	302	.....	.....	150,100	.....	2230	2280	0.176	0.173	.....	60,500

(Continued on page 82)

Table 3 (Continued)

ANALYSES AND PROPERTIES OF GREEN AND DRY SAND ARBITRATION BARS

No.	Analysis—Per Cent Cu.	Si.	Mn.	P.	S.	C.	Step Bar G.C.	Step Bar C.C.	Brinell Hardness D[1]	Brinell Hardness G[2]	Tensile Strength lb. per sq. in. D[1]	Tensile Strength lb. per sq. in. G[2]	Comp. Strength, lb. per sq. in. D[1]	Comp. Strength, lb. per sq. in. G[2]	Transverse Test Load—lb. D[1]	Transverse Test Load—lb. G[2]	Transverse Test Deflection—in. D[1]	Transverse Test Deflection—in. G[2]	Mod. of Rupture lb. per sq. in. D[1]	Mod. of Rupture lb. per sq. in. G[2]
GROUP E (Continued)																				
75A	0.27	1.36	0.66	0.17	0.12	2.98	2.27	0.71	243	251	42,660	42,780	143,700	142,650	2940	2870	0.299	0.256	78,000	76,100
75B	0.47	1.38	0.71	0.18	0.11	3.03	2.22	0.81	249	252	40,950	40,850	147,300	143,950	2720	2655	0.256	0.232	72,200	71,100
75C	0.69	1.40	0.86	0.18	0.12	3.03	2.28	0.75	265	267	39,700	40,560	143,450	146,950	2830	2900	0.264	0.242	75,100	80,200
75D	0.92	1.37	1.03	0.18	0.10	3.01	2.30	0.71	269	281	39,325	38,000	145,700	155,200	....	2780	.....	0.220	.....	73,800
75E	1.03	1.35	1.04	0.18	0.11	2.99	2.39	0.60	271	285	.....	39,500	.....	155,700	....	2510	.....	0.199	.....	66,300
77F	0.13	1.50	0.69	0.13	0.11	2.97	2.66	0.31	216	225	38,070	38,650	133,750	127,750	2530	2655	0.249	0.239	67,000	69,900
77E	0.18	1.55	0.66	0.13	0.11	2.99	2.56	0.43	223	231	39,390	39,300	127,840	134,650	2450	2635	0.216	0.259	64,800	73,000
77D	1.10	1.55	0.98	0.13	0.11	2.88	2.50	0.38	256	258	42,460	44,595	137,460	144,530	2777	2853	0.246	0.226	73,200	74,700
77C	1.63	1.50	1.26	0.13	0.09	2.99	2.35	0.64	273	286	44,920	45,050	148,000	157,950	2565	2750	0.205	0.202	68,100	72,300
77A	1.84	1.49	1.65	0.13	0.09	2.98	2.37	0.61	280	289	.....	44,680	155,300	160,750	2460	2767	0.172	0.189	65,200	72,800
77B	2.16	1.49	1.61	0.14	0.09	2.97	2.36	0.61	287	300	46,040	48,000	152,750	163,100	2735	2575	0.219	0.175	72,500	68,100
84A	0.32	1.65	0.75	0.07	0.12	3.09	2.72	0.37	220	219	.....	.....	.....	.....	2365	2450	0.231	0.237	62,700	65,000
84B	0.67	1.60	0.92	0.07	0.11	3.09	2.61	0.48	233	229	.....	.....	.....	.....	2452	2530	0.226	0.227	65,100	67,100
84C	1.07	1.52	1.13	0.07	0.10	2.85	2.49	0.36	246	245	.....	.....	.....	.....	2420	2755	0.223	0.229	.....	70,600
84D	1.91	1.52	1.37	0.08	0.10	3.01	2.44	0.57	278	270	.....	.....	.....	.....	2210	2713	0.168	0.218	58,600	72,000
84E	2.44	1.52	1.56	0.08	0.10	3.15	2.37	0.78	282	279	.....	.....	.....	.....	2575	2660	0.221	0.198	68,300	70,700
84F	3.26	1.52	1.82	0.08	0.09	2.96	2.34	0.62	299	297	.....	.....	.....	.....	2460	2370	0.213	0.173	61,800	62,900
GROUP F																				
62A	0.33	2.38	0.60	0.17	0.11	2.96	2.45	0.51	248	255	43,216	44,280	144,200	142,266	2648	2559	0.280	0.222	75,300	68,200
62B	0.54	2.42	0.72	0.17	0.11	2.88	2.36	0.52	254	265	44,995	44,650	148,600	148,133	2866	2540	0.262	0.213	75,600	67,400
62C	0.88	2.42	0.84	0.17	0.12	2.93	2.58	0.35	259	268	46,800	41,950	147,683	153,766	2772	2375	0.252	0.200	73,300	62,900
62D	1.35	2.41	1.05	0.16	0.12	2.96	2.53	0.43	266	224	41,900	46,920	145,530	164,500	2783	2215	0.231	0.205	73,800	61,300
62E	1.72	2.37	1.36	0.16	0.11	2.93	2.33	0.60	288	234	46,225	44,650	157,570	166,325	2800	2300	0.237	0.172	73,900	61,300
62F	2.07	2.32	1.66	0.15	0.11	2.85	2.31	0.54	291	241	48,100	48,400	154,970	173,700	2930	2413	0.231	0.186	77,600	64,300
64F	0.27	2.43	0.71	0.14	0.09	2.99	2.70	0.29	217	225	41,200	40,840	132,200	137,800	2780	2548	0.303	0.228	73,800	67,800
64E	0.31	2.50	0.69	0.14	0.09	3.03	2.63	0.43	222	226	40,450	41,570	136,800	141,600	2587	2563	0.271	0.240	68,600	68,100
64D	0.90	2.44	0.72	0.14	0.08	3.00	2.72	0.28	244	248	42,230	43,680	139,100	142,700	2345	2728	0.239	0.225	61,500	73,400
64C	1.84	2.43	1.02	0.14	0.08	2.96	2.38	0.58	255	265	43,770	44,350	146,200	153,200	2667	2673	0.237	0.215	70,800	71,100
64B	2.14	2.42	1.05	0.14	0.08	2.95	2.36	0.59	262	265	42,550	41,550	147,700	153,700	2655	2515	0.262	0.208	70,400	67,500
64A	2.80	2.44	1.23	0.14	0.08	2.95	2.37	0.58	272	273	42,230	40,770	151,600	153,400	2670	2561	0.207	0.212	.....	68,000
65F	0.26	2.44	0.81	0.15	0.07	3.00	2.49	0.51	215	235	39,030	39,362	134,500	143,330	2735	2700	0.280	0.241	72,500	71,800
65E	0.34	2.53	0.80	0.15	0.08	2.95	2.40	0.45	222	241	40,435	40,255	137,900	144,900	2673	2694	0.259	0.229	66,100	71,600
65A	1.09	2.50	1.31	0.14	0.08	2.89	2.37	0.52	252	268	44,630	46,860	156,100	158,100	2690	2833	0.222	0.215	71,400	75,100
65D	1.47	2.47	1.06	0.14	0.07	2.90	2.33	0.57	252	269	45,555	44,316	147,870	153,770	2800	2723	0.220	0.211	75,600	72,100
65C	1.84	2.51	1.18	0.14	0.07	2.91	2.29	0.62	258	269	38,150	45,985	154,570	159,600	2600	2709	0.216	0.213	68,900	71,800
65B	2.10	2.45	1.51	0.14	0.07	2.86	2.36	0.50	282	286	42,000	40,000	157,900	162,050	2615	2747	0.214	0.202	74,000	72,900
78A	0.16	2.48	0.68	0.13	0.11	2.87	2.53	0.34	238	233	40,875	41,100	133,000	136,500	2670	2875	0.277	0.273	70,900	76,200
78B	0.41	2.35	0.92	0.12	0.10	2.77	2.42	0.35	245	241	43,850	42,810	137,700	142,200	2833	2750	0.286	0.252	75,100	73,000
78C	0.62	2.41	0.98	0.12	0.10	2.76	2.35	0.41	256	261	45,490	46,920	145,200	146,300	2890	2921	0.256	0.243	75,000	77,600
78D	1.08	2.46	1.25	0.12	0.10	2.72	2.37	0.35	258	269	46,680	46,220	148,600	153,500	2750	2833	0.230	0.220	73,000	75,200
78E	1.77	2.33	1.58	0.13	0.10	2.75	2.26	0.49	287	300	47,120	49,500	156,500	163,200	2630	2723	0.206	0.206	69,600	72,900
78F	2.21	2.21	1.82	0.14	0.08	2.74	2.25	0.49	300	313	46,440	45,450	161,400	171,100	....	2900	0.188	0.206	61,800	77,000

[1]Dry Sand Bar
[2]Green Sand Bar

the ratio of copper to manganese varies considerably, but it is nearly 1 to 1 when the alloys are present in amounts of from 1.5 to 3.0 per cent.

70. Representative data on the copper-manganese gray iron are graphically presented by plotting the relationship of a property to the copper plus manganese contents (Fig. 4). This is done with the realization that the copper plus manganese content is two variables rather than one, particularly since the ratio of the two elements is not constant. The enormous amount of data required to utilize a method of representation involving three variables makes its use impracticable here. However, the uniformity of the curves obtained by the method employed in this paper justifies its use for purposes of correlation.

Hardness

71. Examination of the data presented in Table 3 and graphically represented in Fig. 4C shows that the copper-manganese addition increases the Brinell hardness very markedly, the increase being slightly greater for the green sand bars. The increasing copper and manganese increase the Brinell 35 to 50 points at about 1.5 per cent each of these alloying metals, the increase in hardness being about 5 points Brinell more for the green sand bars than for the dry sand bars of the same group. Further, the increase is about 5 points more for the higher silicon as compared with the lower silicon iron of the same total carbon content.

72. This relationship of increased hardness and the slight modification of this increase by the silicon content are further substantiated by similar data on groups *E* and *F* which were made with 60 per cent steel in the charge. The data on these heats show that for similar silicon content, the lower carbon iron has a slightly lower increase in Brinell as compared with the corresponding higher-carbon groups *A* and *B*, this lower increase being about 5 points Brinell at about 1.5 per cent each of copper and manganese.

73. The Brinell hardness of the 4-in. blocks, measured 1-in. from the center of the section, also shows a marked increase in hardness with increasing copper and manganese content. At about 1.5 per cent each of copper and manganese, the increase in Brinell is 45 points for groups *A* and *B* and 40 points for groups *E* and *F*, showing that the silicon has very little influence upon

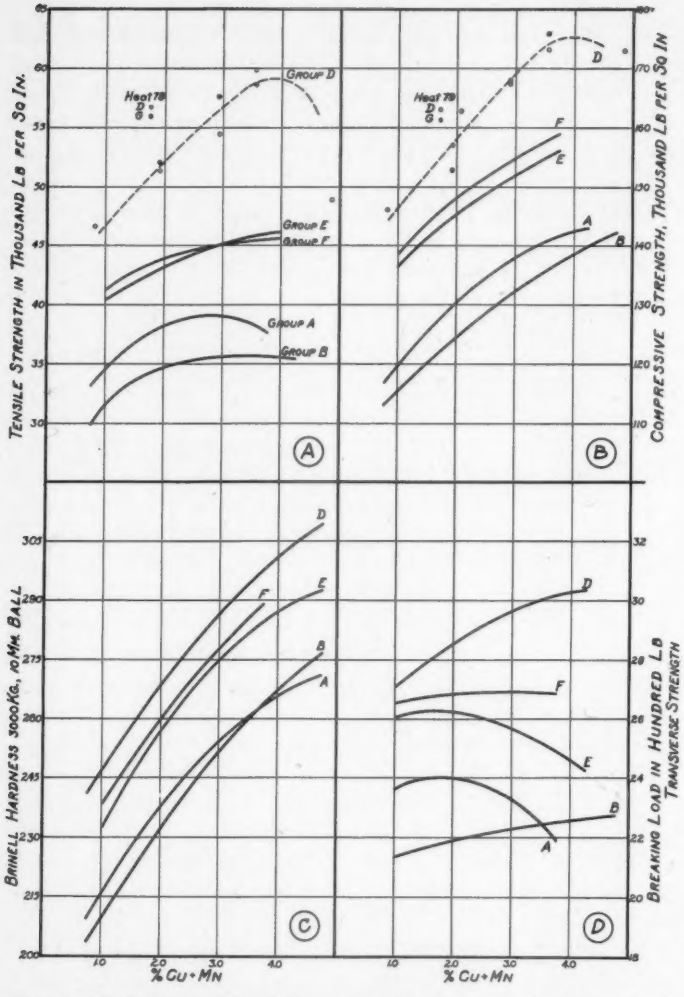

FIG. 4—INFLUENCE OF COPPER-MANGANESE ADDITIONS TO GRAY CAST IRON. A—TENSILE STRENGTH. B—COMPRESSIVE STRENGTH. G—BRINELL HARDNESS. D—TRANSVERSE STRENGTH.

the increase and that the lower carbon manifests itself in the slightly lower increased hardness.

74. The increased hardness with increasing copper and manganese content is further substantiated by the hardnesses of the various sections of the step bars, the data on which are presented in Table 4.

75. The increase in hardness from the center to the exterior of the 4-in. blocks is not affected by the alloy addition; hence, the uniformity of hardness within a section from interior to exterior is not materially affected.

76. The difference in hardness of the 4-in. sections (measured 1-in. from the center) and the ¼-in. sections increases with alloying content, showing that the copper-manganese hardens the iron more in small sections. This increased hardness in the small sections, amounting to 20 points Brinell in the high-carbon groups *A* and *B* and 35 points Brinell in the lower-carbon groups *E* and *F* at 1.5 per cent each of copper and manganese, is not to be accounted for by the assumption of retardation in graphitization, since this increase in hardness can be accounted for readily, as it can be in the case of plain copper gray iron also, by the critical degree of dispersion of the alloying material in the more rapidly cooled small sections and by the tendency of the alloying element to render the more rapidly cooled sections sorbitic. The latter is, of course, most pronounced in small sections and in the iron alloyed with a copper-manganese addition.

Tensile Strength

77. The data show that when copper and manganese are present to the extent of about 1.5 per cent each, both the dry sand and green sand bars of both high and low silicon contents are increased in tensile strength, this increase frequently being 8000 lb. per sq. in. Here again the copper-manganese addition is as effective in high-silicon iron as in low-silicon gray iron. The relationship of copper plus manganese contents to the tensile strengths of the green and dry sand bars of groups *A*, *B*, *E*, and *F* is illustrated by Fig. 4A. The data for heat 79 are plotted as representative of group *D*, since this is the only heat in this group that has been tested to date.

Table 4

STEP BAR BRINELL HARDNESS

GROUP A

No.	Step Bar Section Thickness—in.						
	4[1]		2	1	½	¼	⅛[2]
	Int.	Ext.					
51A	211	232	231	265	269	305	67.5
51B	198	218	227	257	268	333	66.2
51C	200	230	236	269	286	302	66.2
51D	217	242	252	286	299	340	67.1
51E	244	265	281	273	340	...	70.4
52A	170	186	195	221	235	250	65.1
52B	169	187	199	226	236	250	66.8
52C	180	206	209	241	255	262	66.2
52D	193	216	225	257	273	290	64.1
52E	213	243	257	283	302	340	61.9
53E	179	201	201	229	235	250	65.7
53D	184	215	206	239	243	267	54.4
53C	190	217	210	241	255	274	51.0
53A	213	237	238	264	291	302	55.5
53B	207	240	235	274	289	302	50.2
54E	177	197	200	228	238	250	58.7
54A	206	227	225	261	271	281	55.0
54D	196	218	215	255	269	276	65.4
54C	197	227	220	259	260	298	55.5
54B	208	238	235	275	286	302	55.2
55A	172	191	189	228	234	250	51.0
55B	181	207	195	230	242	250	65.0
55C	187	212	203	249	266	250	50.2
55D	196	224	225	268	277	294	56.4
55E	217	245	246	280	299	335	68.3
55F	223	251	247	283	306	358	63.8
76A	170	183	187	225	230	270	67.4
76B	179	203	198	226	246	265	68.6
76C	188	212	207	243	253	...	67.8
76D	198	230	224	260	281	307	67.9
76E	223	253	251	286	316	364	71.5

GROUP B

No.	Step Bar Section Thickness—in.						
	4[1]		2	1	½	¼	⅛[2]
	Int.	Ext.					
47A	163	193	191	216	228	232	46.3
47B	179	203	204	217	240	250	50.0
47C	188	215	218	240	255	254	50.0
47D	199	225	226	269	276	302	53.0
47E	222	252	248	302	306	343	60.5
48A	129	140	148	174	208	230	43.1
48B	149	174	163	192	224	234	46.5
48C	167	187	188	230	254	271	48.9
48D	179	210	203	263	271	277	54.3
48E	208	248	249	296	301	380	65.0
49E	169	200	197	229	241	250	47.2
49D	193	216	212	246	256	277	51.4
49C	196	220	222	255	269	277	51.4
49A	218	240	236	272	293	317	61.6
49B	206	233	228	264	286	302	55.6
50E	161	195	192	207	228	247	46.2
50D	185	212	213	241	255	258	48.9

[1] Brinell hardness of interior and exterior.
[2] Rockwell C.

(*Continued on page 87*)

Table 4 (Continued)

STEP BAR BRINELL HARDNESS

GROUP B (CONTINUED)

No.	Step Bar Section Thickness—in.						
	4[1]		2	1	½	¼	⅛[2]
	Int.	Ext.					
50C	181	213	211	231	255	262	49.0
50A	187	224	224	246	267	277	51.6
50B	196	224	227	255	276	302	52.4
			GROUP D				
79A	219	240	236	255	272	300	52.7
79B	242	262	258	294	310	340	63.1
79C	260	278	278	304	339	350	62.3
79E	263	276	288	323	362	386	68.4
79D	288	300	294	333	364	401	74.6
79F	290	301	302	343	381	...	70.3
80A	213	227	222	263	269	299	67.0
80C	229	238	251	278	294	446	66.5
80B	211	227	234	254	277	297	68.7
80D	229	244	256	286	304	457	67.4
80E	255	268	282	323	348	515	68.3
80F	277	288	300	313	372	550	70.6
81F	242	234	252	325	340	502	64.8
81E	241	250	265	297	337	475	66.7
81D	255	266	279	329	343	351	68.2
81B	258	265	278	325	355	518	68.5
81C	268	280	285	332	362	...	69.3
81A	262	265	285	337	390	550	70.5
82F	210	219	228	254	269	403	64.7
82E	222	235	235	267	286	308	65.4
82D	240	250	260	283	300	327	66.1
82C	258	282	287	316	346	365	67.9
82B	270	282	284	318	346	375	...
82A	293	302	314	346	375	433	71.3
			GROUP E				
73F	206	222	227	248	268	286	65.7
73E	204	230	226	249	261	298	66.3
73C	216	240	242	274	295	335	67.5
73A	221	236	239	279	287	318	67.4
73B	225	236	242	284	297	324	66.6
73D	229	241	248	288	299	338	67.5
74A	208	224	228	252	264	294	65.7
74B	217	234	244	269	274	299	64.6
74C	226	241	251	272	287	321	66.1
74D	240	265	268	287	315	356	...
74E	257	273	275	302	325	380	...
74F	270	283	287	311	355	415	...
75A	227	238	241	261	280	303	64.0
75B	233	242	246	274	286	360	66.5
75C	248	259	258	275	299	340	67.1
75D	248	262	265	269	299	341	68.0
75E	259	266	269	283	318	...	...

[1] Brinell hardness of interior and exterior.
[2] Rockwell C.

(Continued on page 88)

Table 4 (Continued)

STEP BAR BRINELL HARDNESS

GROUP E (CONTINUED)

No.	Step Bar Section Thickness—in.						
	4[1]		2	1	½	¼	⅛[2]
	Int.	Ext.					
77F	197	215	220	243	259	376	...
77E	202	220	220	245	260	377	65.5
77D	223	247	243	275	299	331	67.0
77C	246	275	261	308	311	345	68.0
77A	254	280	282	311	337	385	70.4
77B	260	280	279	327	346	381	70.3
84A	186	198	211	232	240	276	64.4
84B	202	217	229	250	265	296	65.5
84C	216	233	244	269	293	317	67.5
84D	239	255	263	286	315	355	64.8
84E	246	266	270	304	340	369	71.6
84F	255	270	276	310	349	403	70.0
			GROUP F				
62A	216	238	227	253	263	302	62.8
62B	225	244	239	266	263	302	65.6
62C	238	253	248	277	293	317	51.5
62D	242	266	260	291	304	338	55.1
62E	257	281	274	305	321	367	57.8
62F	269	294	288	321	337	378	68.2
64F	200	217	204	236	253	271	48.9
64E	206	219	212	244	256	278	48.9
64D	209	228	217	258	269	291	50.7
64C	230	250	236	285	296	305	54.6
64B	234	254	...	286	297	307	71.8
64A	246	266	254	292	312	340	62.4
65F	207	227	221	248	260	282	50.8
65E	210	232	224	249	259	276	49.5
65A	233	264	254	288	302	340	55.0
65D	232	253	251	269	291	335	54.7
65C	239	265	256	289	304	339	55.9
65B	255	275	262	302	324	351	59.0
78A	210	227	216	229	265	280	51.2
78B	220	238	229	255	276	300	51.0
78C	235	248	244	265	289	309	54.3
78D	232	257	245	283	300	340	54.6
78E	253	271	262	305	328	365	66.6
78F	264	286	282	318	336	338	70.9

[1] Brinell hardness of interior and exterior.
[2] Rockwell C.

Compressive Strength

78. Enormous increases in compressive strength are shown, these increases occurring in both the dry sand and green sand bars of both high and low silicon contents. With copper and manganese of moderate value, 1.5 per cent each, the increase is 20,000 and 30,000 lb. per sq. in.; in heat No. 48, which is very high silicon (3.0 per cent), the increase at approximately 2.5 per cent each

of manganese and copper, is 44,000 lb. per sq. in. as compared with the plain base-iron. The relationship of the copper plus manganese contents to the compressive strengths of the green and dry sand bars of groups *A*, *B*, *E* and *F* is shown in Fig. 4B. Here again the data for heat 79 are plotted as representative of group *D*.

Transverse Properties

79. Table 3 contains the data on the properties of the green and dry sand bars, the various compositions of a given heat being arranged in order of increasing copper and manganese content. These data show that the breaking load of the green and dry sand bars is generally increased slightly, the increase being 100 to 200 lb. at about 2.5 per cent of copper plus manganese for the 1.2-in. diameter bars broken on an 18-in. span. In iron with a higher alloy content than that just noted, there is generally no further improvement in transverse strength. These effects of the copper-manganese additions upon the transverse properties are further substantiated by the transverse properties of groups *E* and *F*. The low-carbon, low-silicon group *E* is not improved beyond 2 per cent of copper plus manganese. (Fig. 4D)

80. The increased hardness produced by fairly high percentages of copper and manganese is reflected in lower deflections but, unlike the plain copper iron, a slight improvement in deflection is produced by the first additions of the copper-manganese alloy.

Total Shrinkage

81. Like copper alone, the copper-manganese increases total shrinkage progressively with greater alloy addition, this increase being about the same for all groups *A*, *B*, *E*, and *F* and amounting to 0.02 in. per ft. at about 1.5 per cent each of copper and manganese.

Influence of Copper-Manganese on Chill

82. When the copper-manganese alloy is added in the ratio used in these tests, it is found that the chill on the chill block decreases from $\frac{5}{16}$ to $\frac{1}{8}$ in. at about 1.5 per cent each of copper and manganese in the high-carbon, low-silicon group *A*. There is a corresponding slight decrease in the chill in low-carbon, low-silicon group *E*. However, the decrease in chill is less than that observed in group *A*. The copper-manganese additions neither in-

crease nor decrease the amount of chill in the high-silicon groups *B* and *F*, even when the sum of copper plus manganese exceeds 4.0 per cent. It is, then, evident that the copper-manganese alloy influences chill much as copper alone does and that its effect is likewise influenced by the silicon content.

Chill in Small Sections

83. The effect of the copper-manganese upon the chill in small sections is closely related to its effect upon the amount of chill on the chill blocks, since in both instances the white iron is due to rapid cooling. The influence of copper-manganese upon the amount of chill in small sections was investigated by the step-bar cast in green sand, described previously. The copper-manganese alloy used in these tests had no influence upon chill of small sections in groups *B*, *E*, and *F* listed in paragraph 6, but when the silicon is lower and the total carbon higher, as in group *A*, the copper-manganese alloy decreases chill slightly. This decrease is about 1-in. as measured from the small end of the step-bar. Thus, in heat 53, the plain iron, 53*E*, had a 1.5-in. chill measured from the tip of the small end of the step-bar, while 53*A*, containing 1.4 per cent copper and 1.4 per cent manganese, had a ½-in. chill. These figures are typical for this group.

Red Shortness

84. The possibility of red shortness in the copper-manganese gray irons was investigated in the same manner as that employed for the plain copper iron. The results of the tests definitely prove that the alloy cast iron has no greater tendency to be red short than the plain cast iron.

Microstructure and Fracture

84. The copper-manganese additions cause a progressive refinement of the graphite. Also, microscopic study reveals the tendency of the pearlitic structure of No. 47*A* and similar heats to be replaced by a fine sorbitic structure with increasing alloy addition.

85. The fractures of the various sized sections are always finer with increasing copper-manganese additions.

Future Research

85. It is intended that future research on the effects of copper in cast iron will include: (1) complete testing of the remaining copper-manganese irons not reported in this paper, (2) the study of copper with chromium in gray iron, (3) the study of copper with nickel in gray iron, (4) the investigation of copper-manganese austenitic cast iron, (5) the investigation of copper or copper with other alloying materials in white cast iron, and possibly (6) the study of malleable iron with plain copper or copper in conjunction with other alloying materials.

86. Some work on the austenitic copper-manganese cast iron has already been done, with encouraging results, but because of pressure on the time available for the project, this phase of the work has been temporarily discontinued. The investigation into the use of copper in white and chilled iron is well under way and a report will follow this paper in a short time.

Summary

87. Extensive data have been presented on 146 compositions of gray iron containing copper as the only alloy addition. It has been demonstrated that the effect of copper is closely related to the silicon and total carbon contents, particularly to the former, thus explaining many of the contradictory statements which occur in the literature on this subject.

88. Similar investigations have been carried out on gray cast iron to which a copper-manganese alloy was added. About 126 compositions of such iron have been prepared; approximately 100 of these have been fully tested and the resulting data reported here.

89. The beneficial effects derived from the addition of copper or copper-manganese alloy to gray iron, particularly the latter, should offer a new field in gray iron production. It is hoped that the data presented here will be a guide as well as a stimulus to the use of such alloy cast iron in industry.

Acknowledgments

90. The work reported in this paper was carried on as a part of the research program of the Michigan College of Mining and Technology with aid provided by the Federal Emergency Relief Administration under projects 31-F2-21A and 31-F2-59. Sincere

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91. The authors also express their sincere appreciation to the Cleveland-Cliffs Iron Mining Company which, under the direction of E. T. Olson, performed a considerable portion of the analytical work and otherwise aided the project. The advice and cooperation received from R. S. MacPherran, chief metallurgist, Allis-Chalmers Mfg. Co., Milwaukee, Wis., and from Ed Nelson, foundry superintendent, Calumet & Hecla Consolidated Copper Company, has been invaluable. Messrs. Garrett, Leisk, Fleming, Maynard, Davis, Nikkila, Bidigare, Barkell, Orem and Shea had active parts in this work and their services are also gratefully acknowledged.

DISCUSSION

CHAIRMAN H. BORNSTEIN[1]: This paper, which Dr. Eastwood has presented, represents a tremendous amount of work, and is certainly a very welcome addition to the literature of alloy cast iron.

MEMBER: We have had a little experience in the use of copper. We had a job with which we had a lot of trouble. Pumps were cast that were supposed to stand about 8000 lb. per sq. in. pressure, and we started to use 1.5 per cent copper. We have 4000 of those castings, machined all over and drilled and tapped, and we had three castings returned. That has been my experience.

MEMBER: What is the machinability in the range of, say, 210 Brinell, 2 per cent silicon, normal 3.40 carbon?

DR. EASTWOOD: We obviously could not make a good estimation of machinability since the best method of doing so is a production test. Copper decreases chill in low silicon iron. While the copper increases the hardness it decreases the amount of free carbide since it decreases chill. The presence of free carbide is detrimental to machinability. It follows, therefore, that copper should improve the machinability of small sections of low silicon cast iron. The final answer must come from a production test.

MEMBER: Have the authors the cost of this method as compared with other methods of obtaining results?

DR. EASTWOOD: That is rather a broad question, but copper and copper-manganese are, of course, much cheaper than many other alloy

[1] Deere & Co., Moline, Ill.

additions. Both are cheap and easy to use. Other than that, I can not give you specific information.

MEMBER: In other words, you believe that the results secured here are obtained more cheaply by the use of copper than any other means.

DR. EASTWOOD: The copper-manganese combination is particularly effective in improving the properties. Thus, the addition of 1.5 per cent manganese and 1.5 per cent copper to the base irons *B* and *F* has increased the properties of the 1.2-in. bars as follows: Tensile strength increased 5000 lb. per sq. in., compression strength increased 20,000 lb. per sq. in., Brinell increased by 57, and transverse strength increased by about 100 lb. Since these effects are not identical to that obtained by other alloy additions, it is quite difficult to answer that question. The choice of alloy additions is quite specific to each individual foundry problem.

DR. J. T. MACKENZIE[2]: I notice that the authors speak a good deal of chill, but we do not have the results. It would not take up much space to add the results of the chill test to these tables, and from my standpoint it would add quite a lot to the paper.

DR. EASTWOOD: On page 21, paragraphs 36, 37 and 38, we list quantitative data on the effect of copper on chill. On page 22, paragraphs 43, 44, 45 and 46, are data on the effect of copper on chill in small sections. Further on in the paper, there are additional comparisons of plain iron with similar iron containing copper plus manganese.

J. A. WOODY[2]: How and where were additions of copper-manganese made throughout your melt?

DR. EASTWOOD: As I mentioned, all of our additions were made either to the receiver or to the ladle, but there are other methods of adding the copper. On page 12 is listed a number of methods of adding copper to the iron, some of which we tried, as explained, and some of which we did not try.

MEMBER: Has anybody any more or less quantitative data on the machinability of nickel-bearing iron versus copper-bearing iron.

J. S. VANICK[3]: I believe if this paper is very carefully read, you will find answers to many of the questions that are raised. This matter of machinability in irons with silicons over 2.0 per cent, is pretty well described by showing that you get an increased chill for the higher silicons. You get it in two ways. You get it if the silicon goes up and you get it if the copper exceeds a certain amount. In contrast, you can add any amount of nickel and the nickel will cut the chill consistently all along the line, whether it is added to a high silicon or low silicon iron, and whether the nickel is a 0.5 or 15.0 per cent. Of course, we never found it necessary to go over 4.0 per cent. That amount will clean out the chill in the chilled face tread of a car wheel casting. That fact has been one of the difficulties encountered in maintaining chill depth in such castings. We have had to balance that effect with a chill forming

[2] American Cast Iron Pipe Co., Birmingham, Ala.
[3] International Nickel Co., New York, N. Y.

element to obtain chill in some of the alloy hardened chill compositions.

One of the first experiences I had with copper occurred a dozen years or more ago, when the laboratory was asked to put some into solution in making torch-proof plates for safes. The composition was made by melting copper in the crucible and spilling it into a ladle of cast iron and pouring the shapes, generally flat plates. They wanted to make these plates burglar-proof in the sense of getting them hard as well as copper-coated, and we hardened the metal some with nickel and nickel chrome, until we got enough nickel into the metal to take up the 6.0 per cent or so of copper. We added about 12.0 per cent nickel finally, and ended with Ni-Resist composition that many of you know about, containing 12 to 14 per cent nickel, 6 per cent copper.

We got a soft metal, and we went back at it another way and started with a hard metal. We added copper until it started to come out of solution again, and it worked to the extent that you were able to get a hard core in the copper surfaced plate with something like 8.0 to 10.0 per cent copper, I believe.

Such other comments as I might have would have to go into paragraph 85, on "Future Research," where several plans are proposed as to what might be done. I have marked some of the points in the preprint, and may have occasion to refer to them as we go along. In the first place, I presume everyone knows that we are dealing with an element that possesses limited solubility. The solubility charts are left out, but they are available in the literature for any one who wants to get hold of them. The solubility in the range of less than 5.0 per cent has not been thoroughly worked out by any one. It is very difficult to obtain a thorough mix. In one of the early pages, the author has made the suggestion that you might add copper ingot in the cupola. We have tried that, and it races down so fast ahead of the other ingredients that it is pretty hard to keep controlled unless you do a lot of mixing later and use precautions to cut it off from any upper charge.

In the data of Fig. 3, the pick-up in strength is accompanied by a considerable hardness increase and means that quite a price is paid for the strength in terms of high hardness, which means slower machinability. If the iron crosses 305 BHN to get 58,000 lb. per sq. in. tensile, it is sure to be very slow to machine.

The matter of chill was discussed to some extent. The deepening of chill with silicons over 2 per cent and the deepening of chill with coppers over 3 per cent definitely limits the extent to which you can go in commercial production without expecting any trouble.

In that connection, there is a theoretical problem on which I would like to get some information. If you add copper to these higher silicon irons and they are age-hardened, what can explain the effects that happen? When you get a chill in an ordinary iron, you add more silicon to reduce the chill. In this case, if you add copper and start to get a chill, any additional silicon is just going to make it worse. Yet if age-hardening is taking place and the copper is soaking up a certain amount of silicon to do a bit of hardening, then the silicon that should be drawing the chill is being taken out of circulation. If you should add more, what is the end point? Do you form more silicide, or do you deepen

the chill? It is something very unorthodox in the behavior of the iron-carbon-silicon system which certainly deserves plenty of study.

The next point is the failure of strength properties to act consistently. In general, when we get an improvement in tensile strength, we expect that transverse, compressive, fatigue, impact strength, etc., increase all along the line, but here we run into conditions where that does not follow. In our particular work, we would ordinarily suspect segregation, and we search for it just as a matter of curiosity. If we cannot find it, there must be some other cause, and in this case there is no explanation made. If the tensile bar machined out of a transverse bar shows more strength (or perhaps it would not if you made a transverse test out of a machined arbitration bar), there might be anticipated some migration or motion of copper either to the surface or the core of the casting which is affecting the strength and ought to be cleared up.

In the matter of structure, I was interested to find that the authors have located copper sulphide spots which have escaped any attention that I or my associates have been able to give this problem in the laboratory, nor have we found crystals of copper as reported by the authors. We found copper globules, and we found a curious cementation of copper along the graphite flake crevices, just like paint film when copper was present in a sufficient amount. I have not found any one who has checked this film formation on the graphite flake envelope, yet I would be interested in having any one try to duplicate that observation.

I would like to point out that properties such as fluidity, thermal conductivity, corrosion resistance, etc., which the addition element may itself possess in a high degree, are not necessarily passed on to the alloyed product to advantage.

On pages 78 and 79, there is an explanation due where the bottom sentence on page 78, referring to the copper-manganese alloy, reads: "The alloy could be added solid in the form of shot when the cupola was tapped, because it melts readily and dissolves in the melt, forming a homogeneous alloy cast iron." And right across on page 79, "However, there is a marked tendency for a preferential solution of the manganese in the alloy by the iron, leaving the copper-rich liquid at the bottom or to be dissolved later." These are very important factors for foundrymen to know, as to whether there is a stratification going on in the ladles, if that is what I interpret it to be, or whether there is a partial solution in one case and some kind of a stratification in the other. We ought to get the algebraic sum of the two statements and find out what has happened.

Returning again to paragraph 8, page 54, the difficulty of getting cast iron and steel scrap free from copper is reported: "Small amounts of copper frequently contained in local gray iron scrap." I am afraid that this condition is likely to become aggravated with time, particularly in this area, and corrective alloy additions will need to be made to eliminate undesirable effects.

DR. MACKENZIE: I do not think Dr. Eastwood appreciated Mr. Woody's question. Mr. Woody is concerned with the practical business of getting copper in the ladle, and I do not see any figures on how ac-

curate the recovery of copper was, whether you got 90, or 95, or 50 per cent recovery. Do you run into occasional instances where the copper is segregated out on the bottom?

DR. EASTWOOD: Under the experimental conditions, it was more difficult to obtain the alloy in solution than in production because we necessarily added the alloy to the receiver or to the ladle. I can answer Mr. Vanick's remarks relative to our statement in the last line of page 78 and a contrary statement in the middle of paragraph 69, page 79, by pointing out that the first obviously refers to "alloy added . . . when the cupola is tapped," a method which would be utilized in foundry production and the second statement refers to results obtained in our experimental work. Admittedly, the conditions under which we added the copper-manganese alloy were not the most favorable that could be utilized in the foundry. It is a mistake to allow the copper or copper-manganese additions to be dumped into a ladle and permitted to settle to the bottom. Obviously they would then be difficult to dissolve. In the few instances in which we made the additions at the spout of the cupola during the tapping operation, we had no difficulty in obtaining complete solution.

A. L. BOEGEHOLD[4]: One of the things that interested me in the paper was the description of the hot shortness test. We have been casting about for methods of measuring hot shortness of metals, principally malleable iron or other metals such as zinc, or zinc base die castings, and I would like to ask Dr. Eastwood if he found that the test that he used was sensitive enough to find the effect on the hot shortness of variations of the base cast iron? In looking over the data in the paper I did not find any difference between the hot shortness of the base cast iron and that of the copper or the copper-manganese cast iron. Was the sensitivity enough to pick out any differences at all?

DR. EASTWOOD: As I said before, any test either in the laboratory or the foundry for hot shortness on any kind of alloy is pretty difficult. We were not able to distinguish any difference in the hot shortness with either copper or copper-manganese additions as compared with plain gray iron.

DR. EASTWOOD (*Written Discussion*): Since Mr. Vanick has touched upon many points, it has been deemed advisable to consider them more leisurely in a written discussion. Those points which require consideration will be taken up in substantially the same order as given by Mr. Vanick.

Concerning Mr. Vanick's remarks on machinability, it should be observed that only in irons having silicon in excess of 2 or 2.25 per cent does the chill increase with increasing copper. Further, even at this high silicon content, at least 3 per cent copper is required to increase chill, while this maximum amount of copper increases with decreasing silicon. The range of composition in which the copper would increase machining difficulties by increasing chill is therefore both limited and outside of usual compositions.

[4] Metallurgist, General Motors Corp., Detroit, Mich.

The solubility of copper in iron-carbon alloys is considered in the orginal manuscript available at the collegé. It is the solubility of copper in the solid iron complex at high temperatures which is of interest. Contrary to Mr. Vanick's statement, 4.5 to 5.5 per cent of copper—considerably more copper than would be desired—can readily be alloyed in all the gray iron bases used in this work.

Apparently it is Mr. Vanick's belief that, as copper and silicon are increased, a vicious circle is set up, causing materially increased chill. Certainly the authors have made no such contention. While we do say that at high silicon, say 2.0 per cent, an increase in the copper from 3 to 4 per cent will increase chill slightly, we did not find that chill would be increased if the silicon were increased in this iron. We cannot subscribe, therefore, to the statement . . . "if you add copper and start to get chill, the additional silicon is just going to make it worse." Perhaps the elimination of this misconception will render the copper-silicon effects on chill slightly less complicated from a theoretical standpoint.

Regarding the relation of tensile strength and transverse properties, it should be noted that the transverse properties involve both ductility and strength. It would be excellent if increased tensile strength were always reflected in increased transverse strength of any metal but, unfortunately, the opposite is frequently true. There is, therefore, nothing necessarily abnormal if an increase in tensile strength is not accompanied by a corresponding increase in transverse strength. Mr. Vanick's suggestion that the behavior of the tensile strength—transverse strength relationship is due to the segregation of copper, must be discounted since the microscopic examination of many complete sections of the transverse bars containing 4 to 5 per cent copper or less, revealed no regional nonuniformity of copper content.

Regarding Mr. Vanick's statement on the observation of copper sulphide, we merely suggested the possibility of copper sulphite, a possibility not yet disproved. The fairly well formed crystals of the sulphide and copper are illustrated in the photographs accompanying the original manuscript obtainable at the college.

Determining the Height of Molten Metal in the Cupola

By Carl Harmon,* Saginaw, Mich.

Abstract

The author points out that unless several complete charges are mixed after melting, it is very likely that the calculated analysis will not be obtained, regardless of the care exercised in charging. This is due in part to the fact that various sectioned portions of the charge melt at different rates. To correct the condition of varied analysis and to facilitate the mixing of several charges in the well of the cupola, the company with which the author is associated has perfected a device which indicates the height of the molten metal in the cupola. The author describes the device and its various advantages.

1. Those who have had the privilege of playing a part in the production of automotive gray iron castings during the past 10 or 15 years, have witnessed great strides in the reduction of variables in the metals used. In the effort to meet competition, and public demand for greater durability and quality, the automobile manufacturer has continually called upon the foundry to produce castings with uniformity having closer tolerances in all their chemical and physical characteristics.

2. We are all willing to admit that in producing iron from a cupola, there are plenty of good alibis for variables. The opportunities for variables do exist, but during the past few years, we have taken the mystery out of a great many of them and we have accomplished this more with the common garden variety of horse sense than through any extensive scientific investigations. Dust preventon and air conditioning have not progressed far enough in the foundry for us to be favored with the aid of very many scientists or efficiency experts.

3. The purpose of this paper is to describe a very simple, but effective method of eliminating one of the most common and costliest variables encountered in producing cupola iron—that of im-

* Chevrolet Motor Co.

Note: This paper was presented at a session on Cast Iron at the 1930 Convention of A.F.A. in Detroit, Mich.

proper mixing. One may charge materials into the cupola of known chemical composition from an accurately calculated mixture, properly weighed and distributed, taking all the usual precautions necessary to good practice, but, unless several complete charges are mixed after melting, it is very likely that the calculated analysis will not be consistently obtained. There are several good reasons for this. We are all aware of the fact that for every sized charge, there exists a certain minimum quantity of molten metal that will insure a proper mixture. That is, if a 4000 lb. unit charge be used, you could not expect to melt down and tap 1800 or 2000 lb. of metal and obtain the calculated analysis. There are some materials that melt later than others, particularly steel bundles and high silicon pig; likewise, the ingredients of the charge having the smaller cross-sections will melt early.

4. It is important then, to maintain a bath of several charges to minimize the variables that exist there. In foundries, such as ours, where forehearths are not used, this mixing must be done in the well of the cupola. Here, there is no way to observe visually how high the metal is before making a tap. Unless iron is running out of the slag hole or slag is running out of the tap hole, one is never sure where his iron is. There is no assurance in just knowing that the slag is running because most of us have seen slag at both places at the same time.

DESCRIBES THE DEVICE

5. The device for determining the height of molten metal in the well of the cupola, shown in Fig. 1, consists of carbon sticks or electrodes extending through the crucible shell and lining. The common electrode is placed immediately above the sand bed and forms the contact that completes the electrical circuit through the molten iron with any one of the other electrodes. In series with each electrode, are two banks of indicating lamps—one that serves the tapper and the other the blast operator. As the iron rises and falls within the crucible, the lights are automatically brought on and off, indicating the height of the molten iron. In our original installation, we used four indicating electrodes but we have recently reduced these to two sets of two each—one set to indicate that the metal is sufficiently high enough to tap and another to signal that the metal is approaching the level of the slag hole.

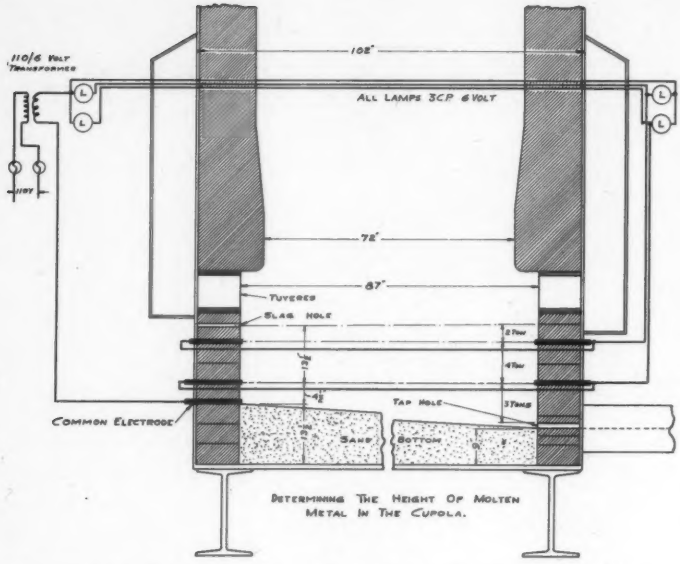

FIG. 1—DEVICE FOR DETERMINING HEIGHT OF MOLTEN METAL IN THE CUPOLA.

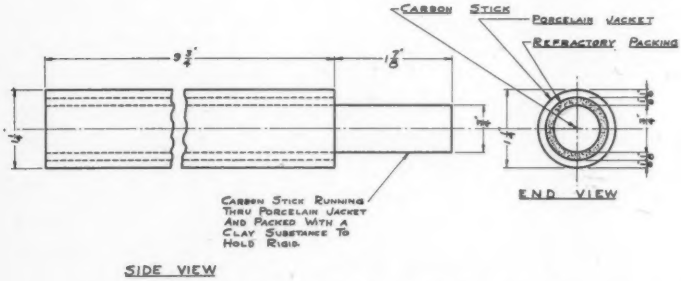

FIG. 2—ELECTRODE USED IN DEVICE IN FIG. 1.

6. As Fig. 1 shows, the burning of the lower lamp indicates that we have 3 tons or two complete charges melted. However, we do not tap until the second lamp is lighted or until we have at least 7 tons of molten iron. This quantity has proved by many series of complete analyses to be sufficient to insure a reliable mixture. Our routine practice is to tap only when both lamps are

lighted but during the tap, the upper lamp will be extinguished. Our distribution system allows approximately two minutes between each 2000 lb. tap from each cupola. This volume of molten metal, remaining fairly constant also minimizes variations in tapping temperature which, in itself, is a decided benefit.

ELECTRODE CONSTRUCTION

7. After experimenting with many types of electrodes, we have found that the most satisfactory type, shown in Fig. 2, is one which is insulated by being rammed tightly, with a refractory cement, into a porcelain tube. The carbon will burn away slightly faster than the porcelain and thus, short-circuiting through the coke is practically eliminated. After each heat, we find it to be burned back about an inch beyond the end of the tube. Failures due to fouling of the electrodes by entrapped slag and coke particles are further reduced by supplying two electrodes on opposite sides of the cupola for each indicating lamp. We have experimented with several refractory cements and porcelain tubes without being able to observe any different results. The current is supplied by the regular 110-volt, 60-cycle light line, transformed to 6 volts.

8. This device, upon which we have gradually improved, has been in constant use in our foundry at Saginaw for several years and although it is not yet entirely fool-proof or 100 per cent perfect, it is the best method we know of and serves its purpose very well.

DISCUSSION

MEMBER: Do the parts of this apparatus have to be replaced after each heat?

MR. HARMON: No, they will last for two heats of between 400 and 500 tons each. In terms of hours instead of tonnage, the heats are from 16 to 22 hours.

MEMBER: What kind of electrodes are used?

MR. HARMON: Three-quarter inch, carbon stick.

H. RAYNER[1]: When the cupola is drained, does the slag cover the end of the electrode, and is there any difficulty when the iron is brought back to clean the electrode again?

MR. HARMON: There are times when we do have difficulty but the porcelain tube does not burn away quite as rapidly as the carbon, and

[1] Dodge Bros. Corp., Detroit, Mich.

the carbon will be back in a 1/2-in. or so. Also, due to the fact we have two of the instruments, one of them usually functions all right.

MR. RAYNER: We tried that in one of our cupolas. It worked satisfactorily excepting that for one thing. We drained the cupola quite often and the electrode was insulated with slag. We only had one electrode.

MR. HARMON: Before we used the porcelain tubes, we found we had shorts, possibly through the linings, or maybe through the coke. As there was nothing to protect the tube from being right next to a large piece of coke, it would short across through the coke.

Measuring and Controlling Pouring Temperatures and Fluidity

By Carl F. Joseph,* Saginaw, Mich.

Abstract

Considering that one of the most important phases of foundry practice is temperature control of the metal, the author describes the equipment to measure temperature. Keeping the instruments in good condition and checking with standards is very necessary to obtain reliable results. A plan for temperature control is outlined as carried out in a plant where the iron is melted in a cupola and superheated in an electric furnace. To establish pouring temperature control it was found necessary to cut down high radiation losses occurring in the ladles; to do this, insulated covered ladles were developed. These are described. Effects of different temperatures of pouring are listed. These include effects on fluidity, which is stated to be not altogether a function of temperature. A study of fluidity and factors affecting it are discussed in detail, together with methods of measuring this property. The relations of mottling, tensile strength, hot cracks, and annealability to temperatures of pouring are discussed.

1. Technical control of all factors entering into the manufacture of castings has been the by-word of all progressive foundries during the past few years. Metal control, sand control, heat treatment control and almost every other control have been practiced, but in very few cases has temperature control entered into the picture. In the writer's estimation, one of the most important phases of foundry practice is the development and maintenance of uniform temperature control throughout all the operations.

2. The first step in developing temperature control is the choosing of the proper equipment to measure the temperature of the molten iron. There is considerable material in the literature covering the various methods to be used to measure temperatures

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Note: This paper was presented at a session on Malleable Cast Iron at the 1936 Convention of A.F.A. in Detroit, Mich.

of molten iron. The most satisfactory temperature measurements of molten iron have been made by using the disappearing filament type of optical pyrometer. The glowing wire of a small electric lamp is blended against the light emitted by the particular hot body as received through a telescope provided with lenses and color screens suitable for the purpose. The lamp situated in the telescope is lighted and controlled from a portable case containing dry cells, variable rheostat and milliammeter. Comparison is made of the current flowing through the blended filament as measured in milliamperes with that shown on a calibration chart previously standardized by similar observations of hot bodies at known temperatures over a given range. It is more convenient to have the instrument calibrated to read directly in degrees temperature.

3. The furnace man is only interested in obtaining comparable readings day after day and, while he is not interested in the question of absolute temperatures, for comparison sake over a period of time and also for comparison with the practice in other foundries, it is desirable to obtain the most accurate readings possible.

Keep Opticals in Good Condition

4. Since the optical pyrometers are used almost entirely by practical men, it is most important that they be kept in A-1 condition at all times. There is a general dissatisfaction with temperature observations and, in many cases, this has resulted in obtaining a wide range of readings, due to the fact that instruments have not been kept in good condition. This may have been caused by dirty lenses, gradually deteriorating filaments, changing milliammeter characteristics, dry cells run down, not picking out the proper part of the stream in taking the readings, etc. Very often the inexperienced operator will sight on a slag streak which shows brighter in the field and thereby obtain a higher temperature reading. All these possible variations cause a difference in calibration and instill a lack of confidence in the operator, which, if allowed to occur, may ruin the value of temperature control in a plant.

5. At the plant with which the writer is connected, three optical pyrometers are available for use in service and one standard milliammeter is maintained in the laboratory, with two standard lamps. This standard equipment is never used in service. It is used only to periodically check the service instruments. The source of heat is the inside of a combustion chamber on a continu-

ous annealing kiln, in which the temperature is very near that at which the optical is used in service and is maintained at a relatively constant temperature during the checking period. A correction for any discrepancy between the standard and service instruments is made when reading the service instrument. In this way, the service instruments always read correct temperatures.

Check with Standard Equipment

6. About once a year (oftener if found necessary) the standard equipment is checked against a standard platinum, platinum-rhodium thermocouple. The source of temperature is a Globar furnace with a refractory tube containing the platinum couple inserted. The optical pyrometer is focused on the inside and bottom of this tube at the hot junction of the thermocouple, giving a true black-body condition. This insures an absolute check on the standard equipment. It has been found that in this way it is possible to maintain a standard within $\pm$ 10° F.

DEFINITE PLAN OF TEMPERATURE CONTROL

7. Having established a means of accurately measuring temperatures of the molten iron, the next step is to have a definite control of the temperatures.

8. In the plant where the author is employed, all of the iron is melted in the cupola, desulphurized in a forehearth and superheated in an electric furnace. The temperature of the cupola iron is read at intervals throughout the day. It is desirable from many angles to melt as hot as possible, as this practice gives less erosion of the cupola lining, better chemical control of the metal and less superheat in the electric furnace. The recarburizing properties of the coke determine the amount we can use and thereby regulates the temperature of our iron at the spout.

9. Iron from the cupola flows into a 10-ton bottom pour, electrically tilted forehearth, where it is desulphurized and mixed. There is a loss in temperature at this point, since the iron is allowed to remain in the forehearth prior to being transferred to the electric furnaces for superheating. It is transferred to the electric furnace in a 3-ton insulated ladle.

10. It is an old custom in the majority of foundries to use pouring ladles constructed of a steel shell with an open top and lined with a satisfactory refractory. The radiation losses in such a ladle are very high and a wide variation in temperature is pos-

sible. It is necessary to superheat the iron very high and handle it rapidly to compensate for the drop in temperature while handling.

11. In the author's plant the amount of superheat formerly required was high due to the fact that in some instances as many as 20 molds were poured from the same ladle of iron and very often it was necessary to pig the last iron. Our practice at that time was to superheat the iron in the electric furnace to 2900° F. This meant that we had to increase the temperature of our iron more than 350° F. The iron was tapped at the cupolas around 2700° F., allowed to desulphurize in the forehearth, was transferred to the electric at about 2550° F. and superheated to 2900° F. The superheated iron was then tapped into 1½-ton open bull ladles and distributed to open-type pouring ladles of 500-lb. capacity. The last iron from these bull ladles would go into the pouring ladles at approximately 2735° F., and then drop to 2540° F. by the time the last iron was poured into the mold. Later in this paper, fluidity tests will be shown where the pouring qualities of our iron drop off very rapidly when poured under 2625° F.

Development of New Ladle

12. To establish pouring temperature control, it was found necessary to cut down on the high radiation losses occurring in the ladles used in transferring and pouring the iron. It is very expensive to superheat metal and, therefore, ways and means to conserve heat were studied. A new ladle, covered and insulated, was developed which greatly reduced the amount of superheat necessary in the electric furnace. This also allowed a 500-lb. ladle of iron to be poured within closer temperature limits.

Maintaining Uniform Temperature Control

13. A great deal of thought has been given to electrical heating equipment which would hold the pouring temperature in the ladle constant. Since experiments in this direction were unsuccessful, it was decided to use the insulated covered ladle. Some of the increase in good melt can be credited to the fact that it is now possible to control the pouring temperature within closer limits than by the old method.

Description of Insulated Ladles

14. Fig. 1 is a time-temperature curve showing the handling

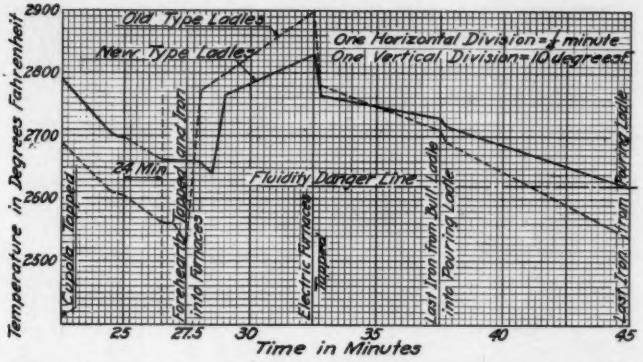

FIG. 1—TIME-TEMPERATURE CURVE SHOWING TEMPERATURES OF IRON FROM TIME IT IS TAPPED FROM THE CUPOLA TO THE LAST IRON FROM THE POURING LADLE, INCLUDING THE PERIOD OF SUPERHEATING IN THE ELECTRIC FURNACE.

of the iron from the cupola to the mold. The old way was described above. A description of the present method follows.

15. Iron is tapped from the cupola around 2800° F. into a forehearth, transferred into a 3-ton covered ladle around 2630° F. and then into the electric furnace where it is superheated to 2830° F. The iron is distributed to the molding conveyors by means of a 2500-lb. transfer ladle and a 500-lb. pouring ladle. Both are insulated and covered. The temperature of the iron at the furnace spout is 2830° F. It drops to 2775° F. in the hot metal crane, and further to 2690° F. in the pouring ladle. The pouring range is usually maintained within 60° F. so that the minimum

FIG. 2—COVERED FOREHEARTH DELIVERING IRON TO NEW TYPE 3-TON BULL LADLE

FIG. 3—NEW 3-TON LADLE DELIVERING IRON TO THE ELECTRIC FURNACES. NOTE COVER (C) FOR FURNACE RECEIVING SPOUT.

temperature of the last iron from the pouring ladle is 2625° F. or over.

16. Illustrations of the insulated covered ladle are shown in Figs. 2 to 9.

17. Iron is now tapped from the cupola at approximately 2790° F. into the forehearths, which have been completely covered

FIG. 4—NEW TYPE 1½-TON LADLE RECEIVING IRON FROM THE ELECTRIC FURNACES. NOTE COVER (A) THAT OPENS AUTOMATICALLY AS CRANE IS LOWERED IN PIT.

except for a small 9 in. x 24 in. slot. This covering is shown in Fig. 2. The new 3-ton insulated type ladle receiving iron from the forehearths is also shown in this figure, while Fig. 3 shows the same 3-ton ladle delivering iron to the electric furnace. The cover for the receiving spout to the electric furnace may also be seen in Fig. 3.

Pouring Ladles

18. The iron after being delivered to the electric furnace is

FIG. 5—NEW TYPE POURING LADLE (C) RECEIVING IRON FROM NEW 1½-TON BULL LADLE (B), AND ALSO IN SERVICE (H) ON POURING CONVEYOR.

FIG. 6—NEW AND OLD TYPE POURING LADLES IN SERVICE ON POURING CONVEYORS.

FIG. 7—CLOSE-UP VIEW OF BOTH NEW TYPE INSULATED AND COVERED (D) AND OLD TYPE (E) LADLES.

FIG. 8—CLOSE-UP VIEW OF 1½-TON BULL LADLE COMPLETELY RAMMED-UP.

superheated to approximately 2830° F. and tapped into the new type 1½-ton bull ladle as shown in Fig. 4. Fig. 5 shows the same bull ladle delivering iron to one of the new type pouring ladles, and also one of the new type pouring ladles in service on the pouring conveyor. Fig. 6 also shows one of the new type pouring ladles along with an old type ladle, which was placed back into service for

this picture. On the extreme right may be seen one of the new type 1¼-ton bull ladles delivering iron to a new type pouring ladle.

19. Fig. 7 is a close-up view of the new type pouring ladle, in comparison with one of the old type. It is interesting to note the heat deflector that was necessary for protecting the iron pourer from the open top of the old type ladle. Fig. 8 shows a 1½-ton bull ladle completely rammed up and ready to go into service.

Teapot Ladles

20. The general construction details of the new teapot pouring ladle are shown in Fig. 9, and consist of 2½ in. of refractory backed up with 1¼ in. of insulation and a ¼-in. metal shell. This shell is first lined with the insulating brick. A removable form is then inserted and the refractory wall rammed into place. The form is then removed and the refractory for the one closed end rammed in. The cover for the open end is then fastened on, and the insulating brick and refractory for this end is placed through the 8 in. x 8 in. opening and spout. The construction of the 1½-ton and 3-ton ladles is practically the same, except for an increase in thickness of the refractory wall, and the use of an additional removable form for ramming the top.

21. The average life of the new type pouring ladle is 42 actual pouring days as compared with a 4-day life of the old type. Although the relining cost of the new type pouring ladle is three times that of the old ladle, the actual cost per day of service for this new type ladle is much less that of the old type ladle, due to its much longer life. The new type ladles require practically no

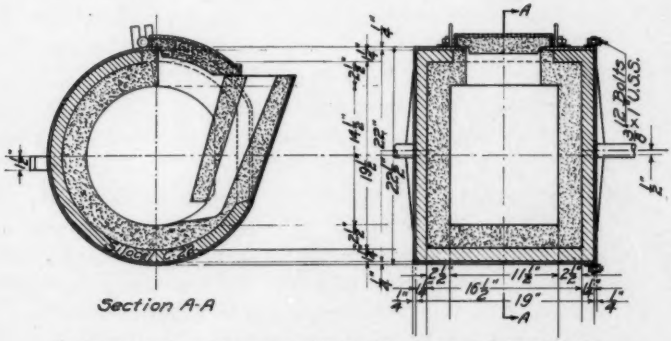

FIG. 9—SECTIONAL VIEWS OF 500-LB. INSULATED POURING LADLES.

patching except around the opening and at the spout. The covers for these bull ladles have an average life of four days.

22. The temperature of the outside shell of the new type ladle is approximately 350° F. as compared with an average temperature of 850° F. on the old type ladle.

23. By comparison of the two curves in Fig. 1, it will be seen that a superheat of 190° F. is now required as compared with 370° F. superheat formerly necessary before the development of the new type ladle, and the change in cupola charge and operation. This change in the cupola charge consists of using a larger quantity of a different kind of coke and the substitution of some of the less expensive makeup charge for part of the pig iron charge. The increased coke cost is entirely offset by the cost of the makeup charge.

Results

24. Based on an average yearly production, the above methods of operation show the following results:

(1) A substantial reduction in the energy consumption required for superheating.

(2) A substantial reduction in the electrode consumption.

(3) Increase in the capacity of the electric furnace.

(4) Reduction in the amount of foundry spillage.

(5) Increase in temperature of the last iron out of the pouring ladle by 75° F.

(6) Reduction in the overall ladle maintenance.

(7) Improved working conditions for the foundry in general, and especially for the iron pourers and shifters due to cooler atmosphere and the ease of handling the new type ladles.

25. The new type ladle is responsible for a substantial saving of the first three items mentioned above, and practically all of the remaining items.

26. The preceding discussion on our practice of making and operating the insulated covered ladle is for the purpose of acquainting the foundryman with the pouring equipment necessary to obtain proper temperature control. Without this, or a similar ladle, pouring temperature control would be almost impossible. It is hoped that some day constant temperature control of iron in the

pouring ladle will be realized. This, without doubt, will justify a considerable expenditure, taking into account the savings obtained in lower fuel costs, lower scrap, and higher casting yield.

FURNACE CONTROL

27. Every furnace installation has its particular problem of temperature control. Many installations still use the old method of judging by eye, leaving the accuracy of operation entirely to more or less guesswork. Indicating or recording instruments showing the fuel or power input are almost indispensable. The general opinion is that electric furnace melting and superheating are simple, when in reality they require more careful control to prevent overheating than most of the other forms of heating. In our case, supplementing the optical pyrometer reading, we have an instrument which shows the total kilowatt-hours input for each ladle of cupola metal added. A given predetermined number of kilowatt-hours are given to each ladle and the temperature checked with the optical pyrometer.

Measuring Temperature of Molten Iron

28. Some plants use a fluidity test to control the temperature at which the iron is tapped, while the most common still used in many plants is the ladle test, consisting of dipping the ladle into the furnace, withdrawing the iron and keeping track of the length of time the metal surface remains free from oxide formation or completely covers it.

29. The fluidity for control of correct tapping temperature in some plants is a stepbar ranging in sections from one inch down to 1/16-in. In other cases, notched spirals of a standard length must be obtained prior to tapping the heat. In a large continuous pouring foundry, spiral test molds are poured every 15 minutes throughout the day. The length of the spiral must fall within predetermined limits. From the standpoint of mold running ability, the fluidity tests mentioned are better than the stop watch test.

30. A method of measuring molten iron which uses a graphite-silicon carbide thermocouple is about to be marketed, which is claimed to indicate accurate temperatures over a period of time. This will serve a much needed want in the field of ferrous melting.

31. Many plants use some means of storing a large volume of iron just prior to pouring. This has a two-fold purpose—to

equalize uniformity of analysis and to maintain a more constant pouring temperature.

Fluidity vs. Temperature

32. It is a known fact that certain melting processes produce a more fluid iron at lower temperatures. How much difference there is in the degree of fluidity between electric, open-hearth, air furnace or Bracklesburg, producing the same analysis iron, is difficult to state. Perhaps the furnace atmosphere, as will be discussed later, is the most important factor. Various fuels used in melting have been mentioned as influencing fluidity. The point is, it is evident that the fluidity of iron is not altogether a function of temperature and that there are many variables affecting fluidity. Of the two, fluidity is more important than temperature, since it is of primary importance to completely fill the mold. Also, the greater the fluidity the more easily the casting will feed and the greater the casting yield.

STUDY OF FLUIDITY

33. Foundrymen are interested in the fluidity of iron because it affects their costs. They look upon fluidity as the property of the molten iron to fill a sand mold completely. Unfortunately, many cases exist where other factors besides the iron or the temperature cause the metal not to fill the mold, which at times is blamed on the metal. Only by a thorough analysis of the many factors involved can the cause be determined.

34. Following are some of the foundry factors which influence the fluidity of the metal, and are often the cause of the poor running quality of the iron:

Core	Hard cores which will not allow gas to escape
	Dense cores which will not allow gas to escape
	Shift of core in mold
	Worn out corebox
Pouring	Haphazard pouring
	Speed of pouring
Sand	Seacoal content of molding sand
	Moisture content of molding sand
	Permeability of the molding sand
Pattern	Design of casting
	Design of gating

35. The usual metal thickness of our malleable iron castings is 3/16 in. or over, which iron is poured at the standard temperature. If it should become necessary to pour castings less than 3/16 in. thick, the pouring temperature must be increased. One big factor in pouring cored light sections is to have a soft permeable core, otherwise, cold shuts and misruns will occur.

Size of Casting

36. When the casting surface is large in relation to the mass, the sections are usually light, and consequently, it is necessary, as a general rule, to increase the pouring temperature of the casting to avoid misruns. Hotter iron must be poured into such castings than that used in the more chunky castings. In other words, the temperature of the iron in either case must be high enough to completely fill the mold.

37. On the other hand, the temperature must not be too high. Fuel costs, especially when electric heat is used, rise rapidly as the superheating temperature is raised, due principally to radiation loss. When iron was tapped at 2900° F., our KWH consumption was approximately 25 per cent higher than when the same iron was tapped at 2830° F. Refractory and furnace maintenance costs also were considerably higher.

38. The pouring temperature has a marked effect on the amount of clay for rebond necessary to maintain the proper bond strength. Also, increasing pouring temperature increases the sand losses from the molding system due to the fact that more sand adheres to the castings. In this manner, the maintaining of a constant pouring temperature facilitates the control of the molding sand.

39. In air furnace practice, very often at the start of the heat, heavy castings, which do not misrun easily, are poured first. Later, as the iron becomes hotter the lighter castings, which are more apt to misrun, are poured.

40. In conveyor molding, where iron is pouring continuously throughout the day, the iron must be tapped at the same temperature at all times to obtain uniform results. Molding conveyors at close proximity to the melting department should take care of the lighter castings, and those conveyors furthest away, the heavier castings.

41. Pouring temperature will depend a great deal upon the kind of metal poured. For any two irons poured at the same tem-

perature, the running qualities are better in the case of the iron having the lower liquidus temperature.

Pouring Time

42. A short pouring time on a casting with large wide gates may mean lower iron pouring temperatures to completely fill the mold than a long pouring time resulting in passing the same amount of metal through restricted narrow gates. Therefore, the length of pouring time must be adjusted on certain castings to conform to the pouring temperature adopted as standard.

43. We have tried to establish a formula for determining the duration of pouring or size of gates for certain classes of castings, but while the information may be useful, it is apt to lead to trouble and the most reliable method is to gate from past experience.

Metallurgical Factors Influencing Fluidity

44. Metallurgical factors influencing the fluidity of iron may be listed as:

Carbon content of metal
Silicon content of metal
Phosphorus content of metal
Nature of raw material in the charge
Desulphurizing with soda ash
Atmosphere

45. The conclusions drawn from the above metallurgical factors as they influence fluidity are from practical observations over a period of many years on white iron made in air furnaces using hand fired coal, powdered coal or oil as fuel, and also metal melted by the cupola-electric process, to be later malleablized. No definite ranges will be given as to the point to which elements must drop before fluidity is affected, but in general, carbon, silicon and phosphorus have an adverse effect on fluidity as they are lowered. The decrease in fluidity is more marked with the lowering of carbon than silicon or phosphorus in the usual run of iron melted. Manganese does not affect the fluidity within the usual limits.

46. The higher the steel content of a charge, the hotter the metal must be heated to obtain the same fluidity, therefore, it can be concluded that increase in steel content of a charge lowers fluidity. This decrease in fluidity has been noted even though the carbon content remains the same.

47. Desulphurizing with soda ash deoxidizes the metal. It

removes the non-metallic materials and this purification of the metals is characterized by an increase of fluidity.

Atmosphere Affecting Fuidity

48. Atmosphere in which the metal is heated has an influence on the fluidity of the metal. We have noted that when the electric furnace is sealed tightly and there is an absence of a flame around the electrode cooling glands, the iron (even though at the proper pouring temperature) does not handle well. The exclusion of air causes a more reducing atmosphere in the furnace which results in this lack of fluidity.

49. This lack of fluidity in metal due to reducing atmosphere is also found in steel melting practice, where steel lacking fluidity is changed to a very fluid state by the addition of a small amount of iron ore. In other words, over-reduced metal is less fluid, and can be quickly changed to a more fluid state by oxidation.

50. In air furnace practice, the amount of oxidation of carbon, silicon and manganese from the original charge to the final iron poured, affects the fluidity. The less the oxidation loss of the elements the better the iron handles in the ladle at the same temperature with the same chemical analysis. Therefore, it is concluded that fluidity is adversely affected by increase in oxidation of the elements. This must not be confused with the over-reduced atmosphere over a molten bath, which, also adversely affects fluidity.

EFFECTS OF TEMPERATURE

Mottling of Iron Due to Temperature

51. The effect of pouring temperature on the mottling tendency of white iron must be viewed from two angles. First, iron which is heated from a lower to a higher temperature; secondly, iron which is cooled from a higher to a lower temperature. In the first case, the cold iron will mottle more easily, and as the temperature is raised, without change in chemical composition the mottling will become less. In the second case, the hot iron heated to say 2900° F. and cooled to 2600° F. does not change much in mottling tendency. These tests were made by pouring a round test sprue 7 in. long with one end 1½ in. in diameter, the other 1¾ in. This test specimen is used at our plant for mottle control.

52. A more sensitive test for determination of the mottling tendency vs. cross section area as affected by temperature is shown

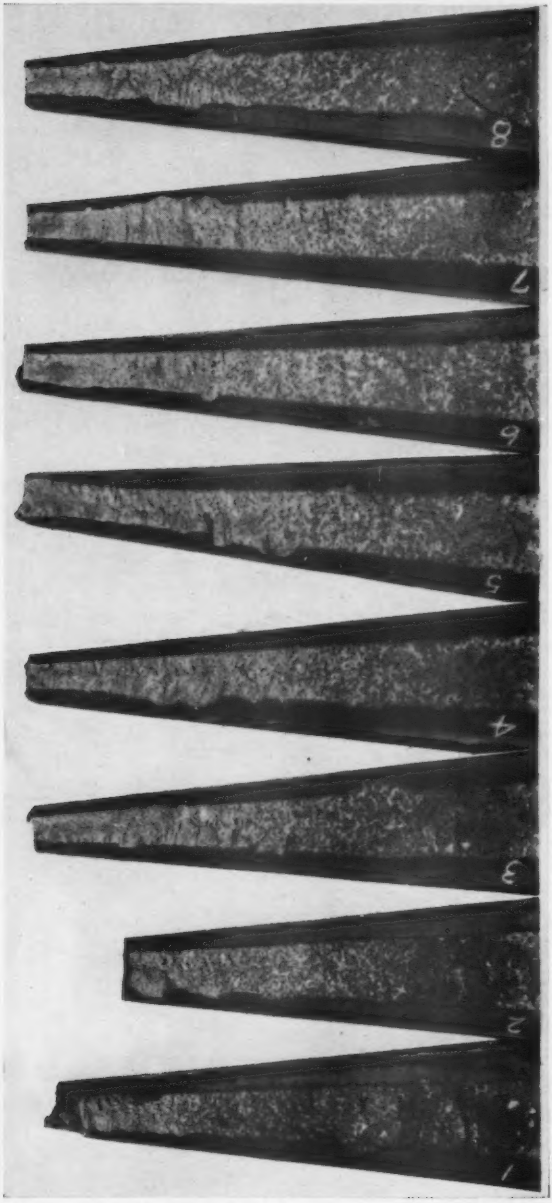

FIG. 10—TEST WEDGES, SHOWING EFFECTS OF POURING AT DIFFERENT TEMPERATURES.

in Fig. 10. These wedges are 12 in. long, 1 in. square at one end and 3¼ in. at the large end. A ⅝ in. slot to facilitate breaking is cast the entire length of the wedge.

53. Fig. 10 shows eight wedges. Those marked 1 to 4 inclusive were poured from the same iron heated from 2600° F. to 2900° F. No. 1 was poured at 2600° F., No. 2 at 2700° F., No. 3 at 2800° F. and No. 4 at 2900° F. It is noted that No. 1 shows the most mottle. No. 2 less and Nos. 3 and 4 about the same.

54. Wedges marked 5 to 8 inclusive were poured from the same iron as wedges Nos. 1 to 4, after being held hot in the furnace for 5 minutes. No. 5 was poured at 2900° F., No. 6 at 2800° F., No. 7 at 2700° F., and No. 8 at 2600° F., all from the same ladle of iron. It will be noted than No. 5 shows the least mottle, Nos. 6 and 7 about the same, and No. 8 increasing slightly in mottling tendency. These tests were repeated a number of times with the same results as shown.

55. We have noted that certain castings with a very thin wall next to a core will show mottled areas in the light wall section and perfectly white in the heavy section when poured at a temperature over 2850° F. This suggests the possibility that carbon may be thrown out of solution when iron is heated too hot and cooled too rapidly in the light sections. Another theory for these mottled areas is that the hot iron running over the sand heats the mold and allows the iron to cool more slowly. The same iron poured into the same casting at a lower temperature does not show the mottled areas in the light sections.

Effect on Tensile Strength and Hot Cracks

56. A study of the effect of pouring temperature on tensile properties was made covering a period of many weeks. Tensile bars were poured at 2600 to 2900° F. from specially melted iron and from production iron. No definite conclusion could be drawn as to whether hot or cold poured bars showed any better physical properties. Some tests showed slightly higher strength when poured hot and the next run higher when poured cold. Generally, however, we prefer to pour our test bars on the hot side, which gives us a cleaner bar.

57. We also had the same experience when trying to determine the effect of hot and cold iron on hot cracks. Some tests showed hot iron to cause more cracks and again cold iron showed more hot cracks. The tests were run on a production job which

was prone to hot cracks. If anything, the cold iron had a tendency to show less hot cracks, although the difference was so slight no preference could be made.

58. It is quite possible that fluidity is the controlling factor in the cracking tendency of lower carbon iron. As stated before, lower carbon iron adversely affects fluidity. In the production of white iron castings for malleablizing, every foundryman knows that the carbon content of his metal must be held above a given minimum, otherwise, hot cracks occur. This same condition exists in steel casting practice where high carbon steels remain fluid in the mold for a longer time and pieces cast from these steels are less liable to crack than lower carbon steels. While fluidity may be responsible for non-cracking, it surely has no bearing on the cracking that takes place after the casting has completely solidified, but still at a high temperature, unless the internal strain in a casting increases with less fluid iron.

59. In general, hotter iron is preferred by the foundryman, and less scrap is poured when iron is on the hot side. Better still, temperature control will insure the same temperature iron every day and hold scrap losses, due to temperature, to a minimum. Cold shuts, misruns, and shrinks very often are the result of too low pouring temperature which can easily be avoided.

Effect on Annealability

60. Pouring temperature as it affects annealability was studied on iron poured from 2550 to 2775° F. at the mold. Three samples were poured from the same ladle. The first was poured as soon as possible after transferring to the ladle, at a temperature of 2775° F. Another test bar was cast from the same metal after holding 2 minutes in the ladle. A third sample was cast after holding the metal long enough to just flow into the mold. This temperature was about 2550° F. The temper carbon distribution is shown in Fig. 11. These test bars were annealed on two different cycles—one in which the iron was brought to temperature at 400° F. per hour to 1700° F., and the other 176° F. per hour to 1520° F. and 36° F. per hour to 1700° F. The former cycle gave coarse carbon distribution, while the latter fine temper carbon distribution. Microscopic examination showed the same time for decomposition of the cementite in each of the three samples on the fast heating up and much less time on each of the three samples

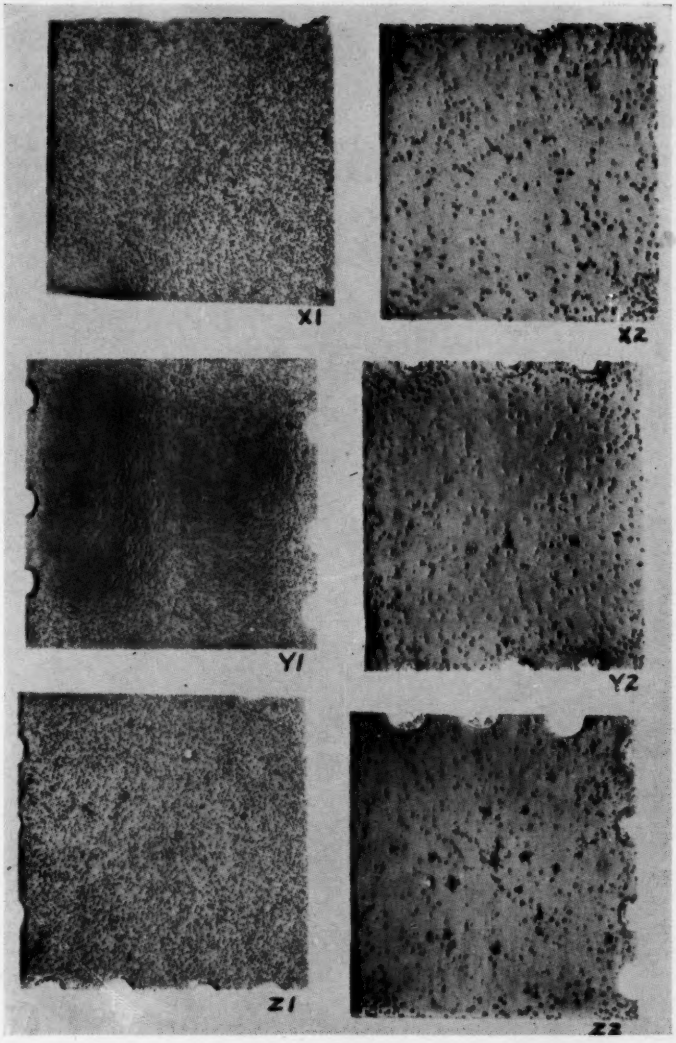

FIG. 11—EFFECT OF HEATING RATE AND CASTING TEMPERATURE ON TEMPER CARBON DISTRIBUTION. IRON CONTAINING 2.73 PER CENT CARBON, 1.05 PER CENT SILICON, 0.34 PER CENT MANGANESE, 0.11 PER CENT SULPHUR, AND 0.05 PER CENT PHOSPHORUS. THOSE SPECIMEN MARKED X1, Y1 AND Z1 WERE HEATED FROM 1300 TO 1520° F. AT 176° PER HOUR AND THEN FROM 1520 TO 1700° F. AT 36° PER HOUR. SPECIMENS MARKED X2, Y2 AND Z2 WERE HEATED FROM 1300 TO 1700° F. AT 400° PER HOUR. SPECIMENS X1 AND X2 WERE POURED AS SOON AS POSSIBLE AFTER TRANSFERRING TO THE LADLE (TEMPERATURE WHEN TRANSFERRED ABOUT 2775° F.) SPECIMENS Y1 AND Y2 WERE HELD IN LADLE 2 MINUTES AFTER TRANSFERRING. SPECIMENS Z1 AND Z2 WERE HELD UNTIL IRON COULD JUST FLOW INTO MOLD (TEMPERATURE ABOUT 2550° F.). THE STRUCTURES SHOW THE EFFECT OF HEATING RATE AND CASTING TEMPERATURE ON THAT TEMPER CARBON DISTRIBUTION.

on the slower heating up cycle, as would be expected from the difference in temper carbon distribution.

61. The bringing up to temperature on certain irons has a pronounced effect upon temper carbon distribution, and, therefore, upon the annealing time. The conclusion is that the pouring temperature does not affect the rate of cementite decomposition.

Measurement of Fluidity

62. In studying the effect of pouring temperature, one naturally thinks of its effect upon fluidity and a means for measuring fluidity. For a number of years the writer employed the fluidity test of Saeger and Krynitsky used in their work on fluidity at the Bureau of Standards. Figs. 12, 13 and 14 show this equipment in detail, which was described in their work published[1] in the A.F.A. 1931 TRANSACTIONS.

63. The casting method employed is as follows: A test ladle

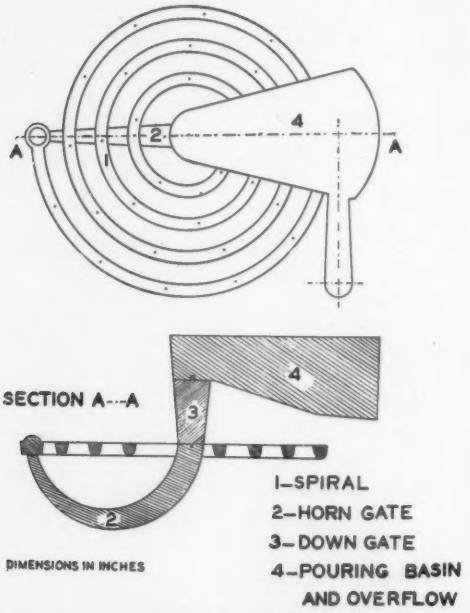

FIG. 12—ASSEMBLY OF FINISHED PATTERN USED FOR DETERMINING THE RUNNING PROPERTIES OF METAL.

[1] C. M. Saeger, Jr., and A. I. Krynitsky, *"A Practical Method for Studying the Running Qualities of a Metal Cast in Foundry Molds,"* TRANS. A.F.A. vol. 39, pp. 513-532, (1931).

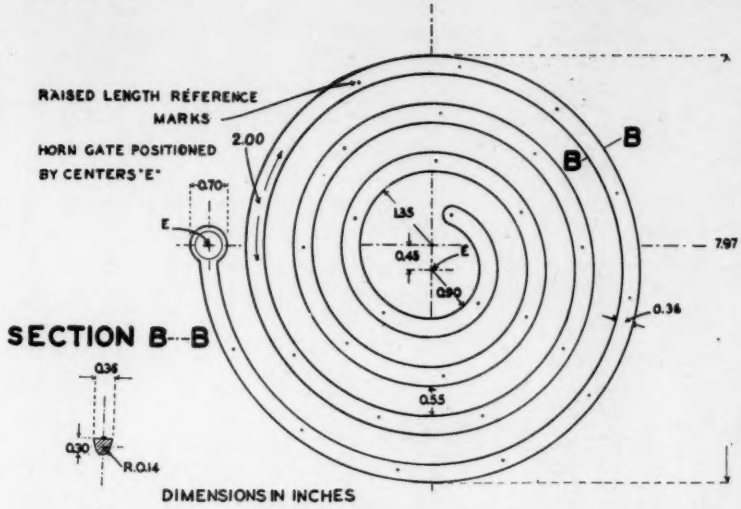

FIG. 13—DIMENSIONS OF SPIRAL IN FINISHED PATTERN FOR DETERMINING RUNNING PROPERTIES OF METAL.

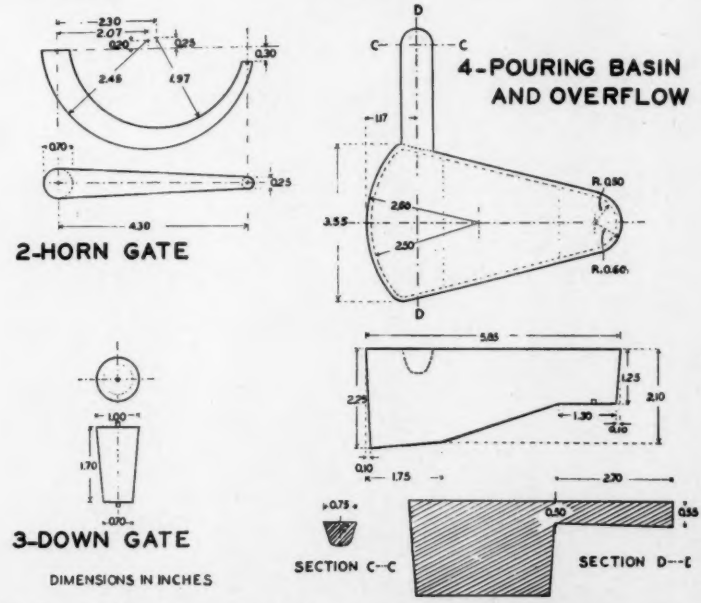

FIG. 14—DIMENSIONS OF HORN GATE, DOWN GATE AND POURING BASIN IN THE FINISHED PATTERN USED FOR DETERMINING THE RUNNING PROPERTIES OF METAL.

holding the proper amount of iron (about 5 lb.) is poured as rapidly as possible into the pouring basin, (4) in Fig. 12, which in turn feeds the metal through the downgate (3) and through the horn gate (2) into the outer end of the spiral (1). By means of the overflow attached to the pouring basin (4) a constant pressure head of molten metal can be maintained. Reference marks are placed at a 2-in. intervals along the spiral to aid in determining its length quickly. The total length of the spiral is 60 in. Figs. 13 and 14 show construction details of the fluidity pattern.

64. The fluidity molds are made of production green sand and must be prepared as nearly the same as possible each time.

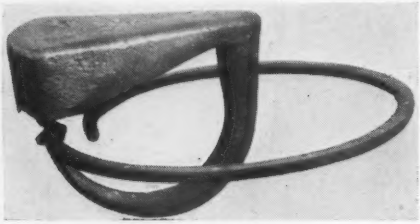

FIG. 15—FLUIDITY SPIRAL (24 IN.) POURED AT 2700° F.

Both cope and drag are thoroughly vented. Fig. 15 shows a spiral poured at 2700° F., which is 24 in. long.

65. The fluidity of the iron is affected to a great extent by the variation in ramming and venting of the mold. In the preparation of molds for the fluidity tests, we found that the most satisfactory method was to hand ram and thoroughly vent. Invariably machine jolting and squeezing shortens the length of the spiral by making the mold too hard, and when the mold is jolted and squeezed too little it breaks, therefore, hand ramming is preferred.

66. No tests were run on effect of moisture and permeability of the sand, but the gas pressure developed in that part of the mold not occupied by the metal retards the flow of the iron to a great extent by increased moisture, increased amount of seacoal, and decrease in permeability of the sand. Pouring temperature of the metal can be lowered if all of the factors are favorable.

Determining Fluidity Danger Temperature

67. Periodically, we check the fluidity of our iron to deter-

mine whether it is possible for us to pour at a lower temperature. There is a fairly constant loss of heat from the time the iron leaves the electric furnace until the last iron is poured from the pouring ladle. Therefore, if the temperature at which there is a marked drop-off in fluidity is lower, the temperature of the electric furnace can be lowered and vice versa. From the temperature-fluidity curve this danger point can be noted and no metal should be poured much under this temperature, otherwise, misruns or cold shuts will occur.

68. To accurately establish this fluidity danger point it is necessary to average up a considerable number of tests. We have noted that this drop in fluidity is about 20° F. lower at present than it was a year or two ago. This means that we can heat our iron 20° F. lower in the electric furnace without danger of misruns, providing our drop in temperature in handling the iron remains about the same.

69. The length of the spiral over a period of time does vary considerably at a given temperature. It is important to study the point at which the length deviates from a straight line when plotting the curve. Usually temperatures are taken at 20° F. intervals.

70. To get the most consistent results, besides molding the same each time, the following precautions have been found necessary:

The molds must be thoroughly vented, both cope and drag. This helps to take care of any variation in sand from month to month.

Molds should be poured as soon after they are made as possible. Molds allowed to stand overnight show wide variation in results. We have tried to pour tests from 50-lb. ladles, but our results were not very uniform until we poured each test individually from a small test ladle.

Method of Pouring Fluidity Tests

71. About five pounds of iron is dipped with a test ladle, previously heated, from the transfer ladle. The optical pyrometer is set at 2700° F. and sighted on the iron in the ladle. When this temperature is reached, the iron is poured into the pouring basin, (4) Fig. 12, as rapidly as possible. This is repeated at 20° F. intervals down to 2560° F. When pouring the iron, it is important to stop when the molten iron runs into the overflow at-

Table 1

FLUIDITY TEST READING TAKEN THREE YEARS AGO

Pouring Temp. Degs. F.	Length of Spiral in Inches
2720	11.25
2700	11.0
2680	10.5
2660	10.5
2640	8.5
2620	7.0
2600	5.5
2580	2.0

Table 2

FLUIDITY TEST READINGS TAKEN TWO YEARS AGO

Pouring Temp. Degs. F.	Length of Spiral in Inches
2700	20.0
2680	18.5
2660	18.5
2650	13.0
2620	10.0
2590	6.0

tached to the pouring basin. This insures a constant pressure head of molten iron. The molds can be dumped and shaken out a few minutes after being poured and the length of the spiral measured from the reference points which are placed 2 in. apart. The longest spiral we have poured from white iron is 26 in.

Table 3

RECENT FLUIDITY TESTS

"B" Unit			"C" Unit		
Pouring Temp. Degs. F.	Length of Spiral in Inches		Pouring Temp. Degs. F.	Length of Spiral in Inches	
2710	25.0		2710	26.0	
2685	19.0		2685	23.0	
2665	19.5		2665	22.5	
2640	17.0		2640	22.5	
2620	17.0		2620	15.5	
2595	12.0		2595	15.5	
2575	11.5		2575	14.5	
Moisture	Permeability	Bond	Moisture	Permeability	Bond
4.3 per cent	50	5.8 lb.	4.0 per cent	55	6.5 lb.

72. Readings taken 3 and 2 years ago showed the results given in Tables 1 and 2 respectively.

73. It will be noted that in both sets of readings the fluidity drops off at 2660° F. These represent the average of many tests.

74. Recently on a series of tests the drop in fluidity occurred at a lower temperature, as shown in the data of Table 3. It will be noted from these tests that the drop in fluidity occurs at 2620 and 2640° F. respectively.

75. During the past 4 years, we have used the same standard equipment for checking our optical pyrometers. It might be thought that 20° F. is not within the limit of error of the instruments, but since the average of all results indicates the break in fluidity to occur between 2620 and 2640° F. against 2640 and 2660° F. formerly, we have been able to hold our iron at a 20° F. lower temperature at the electric furnace with good results.

76. Aluminum (0.01 per cent) was added to the iron in a series of spiral tests. The drop off in fluidity occurred around 2635° F. as shown in Table 4. On iron to which 0.75 per cent copper was added, the data of Table 5 were obtained. The drop-

Table 4

EFFECT OF ALUMINUM ON FLUIDITY

Pouring Temp. Degs. F.	Length of Spiral in Inches
2700	24½
2680	19
2655	17¾
2635	17
2610	13
2590	10
2570	8

Table 5

EFFECT OF COPPER ON FLUIDITY

Plain Iron Length of Spiral in Inches	Pouring Temperature Degs. F.	Copper Iron Length of Spiral In Inches
23.0	2685	20.0
20.5	2665	20.0
21.0	2640	19.0
20.0	2620	18.5
16.5	2595	15.0
14.5	2575	13.0

Table 6

EFFECT OF PHOSPHORUS ON FLUIDITY

Phosphorus Iron Length of Spiral in Inches	Pouring Temperature Degs. F.	Regular Iron Length of Spiral in Inches
24.00	2725	20.0
21.00	2700	18.0
19.00	2680	16.0
16.50	2655	16.5
15.00	2635	12.0
14.25	2610	12.0
6.25	2590	12.5
5.00	2570	7.0

off in fluidity occurred on both irons at 2620° F. regardless of the addition of copper.

77. Ferrophosphorus was added to the regular iron in amounts up to additions of 0.10 per cent—the regular iron being 0.05 per cent phosphorus. The 0.10 per cent addition gave the length of spiral as given in Table 6. With this is listed the data for the regular iron.

78. The iron to which phosphorus was added shows a break in the curve at 2610° F. whereas, the plain iron is somewhat higher, although not as distinct as in most of the tests. The phosphorus addition does lower the danger point of fluidity slightly.

CONCLUSIONS

79. It is recommended that foundrymen who are interested in obtaining better operation, give some attention to improving the control of the pouring temperature of their metal. It is true that to maintain accurate control of pouring temperature, a definite program must be mapped out and adhered to in order to obtain the desired results. Most foundrymen recognize that fluidity and pouring temperature are important factors in casting technique and that very little is known about controlling them. Any foundry having a technical organization will find it an easy matter to install and maintain pouring temperature control, which should pay good dividends from the very start.

DISCUSSION

MEMBER: I would be interested to know if the author has arrived at any conclusion as to why the metal has less fluidity when a high percentage of steel scrap has been used in the charge.

MR. JOSEPH: Usually, when you make up a charge which is high in steel scrap content, there is more carbon, silicon and manganese lost in melting down, and I imagine that when you oxidize the elements, you possibly have more oxygen in your iron as poured, and there is a possibility that the increased oxygen content of the metal decreases the fluidity of the metal.

W. R. BEAN[1]: There are two questions which I would like to ask. One relates to the use of pyrometers, and incidentally our experience agrees very fully with what the author has recorded. I have frequently had occasion to question whether a pyrometer in the average foundry is a help or a hindrance. If it is not accurate, it is worse than no pyrometer, and the local facilities for standardizing are generally inadequate. If groups in the large industrial centers could obtain standard instruments, I think that would be a very profitable investment, a sort of cooperative proposition so that they would have some place near at hand to check and standardize their working instruments instead of having to send them to the Bureau of Standards, or some other laboratory, at a distance.

But the question I wanted especially to ask, in reference to the measuring of temperatures, is whether the author has found any condition, or set of conditions, other than those pertaining to the instrument proper, that interfere with the accurate reading of metal temperatures? That is, do atmospheric conditions, light conditions, dust films, or any factors of that kind, act to make the readings inaccurate to any appreciable degree, or can we depend upon a reading, from the standpoint of accuracy, with the instrument in the hands of a skilled operator indicating closely what the actual metal temperature is?

MR. JOSEPH: When we first started to measure the temperature with optical pyrometers, we employed college graduates who possibly were more interested in obtaining accurate data. We had these college men on the job for a number of years, and after we found that they could do the job well, we put it in the hands of the operators on the furnaces.

We noticed that any fumes or smoke interfered, and it is necessary for the operators who read the metal temperature to stand in a way so that these fumes did not interfere.

Also, you naturally cannot take any readings on a bath iron that has any slag or oxide. With the cupola, towards the last of a tap very often, there is some slag or oxide which covers the molten stream, and if any readings are taken at that time, they are usually too high because with the optical pyrometer the slag shows a higher reading than does the molten iron. Therefore the operator naturally has to watch that.

The operator has to know that there are certain conditions which

[1] Vice-President, Whiting Corp., Harvey, Illinois.

interfere, and those are slag, oxide films, smoke, or fumes, but it is possible to take readings on the metal at points where these adverse conditions do not exist. Very often, especially on windy days, we have noticed that operators have to stand in one place or another, away from the wind, to avoid that condition.

MR. BEAN: There is a very definite technique that has to be developed and followed to have the readings really representative and valuable, because if they are not accurate, they are, I feel, worse than visual observations coupled with experience and good judgment.

The other question which I want to ask relates to the amount of steel in charges. That is, a high percentage of steel in direct melted air furnace charge might be stated at around 15 to 20 per cent, very seldom in excess of 20 per cent in a charge of that kind, but I believe that when you refer to a high percentage of steel, it represents a larger proportion of the charge than that. I am interested to know what you consider a high percentage.

MR. JOSEPH: When I made air furnace iron we never went as high as 15 per cent. We used to use from 4 to 10 per cent steel. I have in mind the cupola practice, where we have increased the steel over a period of years from, say, 20 to 50 per cent. Now when 50 per cent steel is used, with the same carbon content at the spout of the cupola, which can be obtained by adding more coke, with the chemical analysis identically the same, there is a lack of fluidity in the higher steel charge over the lower steel charge.

MR. BEAN: In other words, the product of any melting process retains some of the characteristics of the materials from which it comes, going probably quite a long way back. If we could trace those things out completely, I believe that would be what we would find to be the case.

MR. JOSEPH: I do not know whether that is true, but I believe that 80 per cent, or a rather high percentage of the difficulty that is experienced with metal at the spout, is due to raw material or to changes in raw material. Whether it is pig iron or steel or fuel or whatever it might be, it has been definitely proved in our plant, for the past 10 or 15 years, and it is possibly the experience of most people that have had any iron trouble, that very often it is traced back to the raw material.

MR. BEAN: I am bringing out these points because you have had more opportunity to determine the facts than most of us have had, and have studied them more exhaustively, and no paper can cover all of the important factors that pertain to what is put down. These facts are very important and they are not as fully understood in the smaller plants. I feel that you have contributed and can contribute much to the knowledge of many of us who do not have the facilities and the opportunities for tests and observations.

R. F. HARRINGTON[2]: Bearing in mind the care with which the pyrometer is used, we have used them very successfully for at least 10 years. We have a standard pyrometer that we check with the manu-

[2] Metallurgist, Hunt-Spiller Mfg. Corp., Boston, Mass.

facturer, and two other pyrometers that we use daily. In the foundry, a man takes readings of the pouring temperature each morning and checks with the man at the furnace who is taking readings at the furnace. We feel that this method is effective indeed, providing precautions are taken as outlined both by Mr. Bean and Mr. Joseph.

Now the speaker could, I think, have brought out one important factor in relation to the insulated ladle, and that is its merit insofar as reduction in the cost of alloy additions is concerned. For example, an insulated ladle of 750 lb. capacity will easily pour the entire 750 lb. into an alloyed casting, where you would otherwise have to have a 1000 or 1200 lb. of iron for the same number of castings, and therefore have a consequently higher alloy cost in the insulated ladle. This is a very important factor, both from the standpoint of the temperature at which a group of castings is poured, and also in keeping the alloy cost down. We feel, in our practice, that the insulated ladle is an extremely effective means of handling this type of material.

MILTON TILLEY[3]: I would like to ask Mr. Joseph how he arrived at the conclusion that the best method of controlling the fluidity of the metal was by measuring the temperature, bearing in mind that fluctuations in the carbon percentage cause a variation of fluidity with the same temperature, also the same with silicon and combinations of silicon and carbon. This also being true of metal that is "killed" too much, and at the other extreme of metal that is too highly oxidized, it seems to me that the best control is by measuring the fluidity.

MR. JOSEPH: Over a period of time we do not make any changes in our charge. For instance, we might operate for 6 months or a year on the same steel content, within very close limits. If we are operating around 48 per cent steel, we might vary 1.0 or 2.0 per cent, which no doubt has a slight bearing, but not as much as 10 or 12 per cent would have. Therefore I do not believe that we are justified in making any change in the temperature of the iron by a slight change, for instance, in our steel content. Our analysis of the iron is possibly very much the same from year to year, although it does vary according to the raw material. Periodically we do make these fluidity tests. If they show that we must pour the iron at a higher or a lower temperature to attain that point at which the temperature drops off rapidly we will have to change our heat. We are actually pouring iron at a lower temperature now than we ever have, and the reason, I believe, is that the fluidity of our metal is higher; that is, it flows to a greater length at the same temperature than it did a year or two ago.

MR. TILLEY: That is the point I wanted to make. If you use fluidity tests to check temperature measurements by the optical pyrometer, why not use the fluidity test all the time?

MR. JOSEPH: If we had to pour a fluidity test for every ladle that we tap, we would have to make about 500 or more fluidity tests a day. These 1½-ton ladles, let us say, hold about 1¼ tons of metal, and if you

[3] Metallurgist, National Malleable and Steel Castings Co., Cleveland, O.

are pouring about 800 tons of metal, it would require close to five hundred molds a day to be made, to check every tap. That would be quite a job. It is a lot easier to take an optical pyrometer and establish a relationship between the fluidity and the temperature.

Report of Steel Division Committee on Test Coupons

The Steel Division Committee on Test Coupons, which presented the following report, is composed of the following: J. M. Sampson, General Electric Co., Schenectady, N. Y., Chairman; C. F. Pascoe, Supt., Foundry Division, Canadian Car & Foundry Co., Montreal, P. Q., Canada; Lieut Comdr. A. J. Welling, Naval Gun Factory, Navy Dept., Washington, D. C.; Fred Grotts, Continental Roll & Steel Foundry Co., East Chicago, Ind.; Lieut. G. D. Linke, Navy Dept., San Diego, Calif.; Wm. C. Hartmann, Bethlehem Steel Co., Bethlehem, Pa.; and H. D. Phillips, Dodge Steel Co., Philadelphia, Pa.

J. M. SAMPSON[1]: Due to the short time interval between the Toronto Convention and the appointment of our Committee, it seems wise to make the report rather short.

Regarding test bars taken from the castings themselves, results from the tests thus far received are not too alarming. There has been very good correlation between tests from the castings and from coupons in some instances, while in others results were not so good.

One thing that should be done in gathering this information, is to obtain a clear picture of just where the test pieces are taken from the casting, in relation to the risers, adjoining sections, proximity to the gates, etc. All these points have certain vital effects on the results obtained. Before we can submit any report on which definite conclusions may be based, at least another year will be required.

I would like to turn over this discussion to Dr. White to give us some definite conclusions, or at least certain trends, from his observation and tests on a good many commercial castings produced for certain clients.

DR. A. E. WHITE[2]: We have done some work for the purpose of ascertaining whether or not there was any material difference between separately and integrally cast test lugs. We also were particularly interested in ascertaining what the properties in the castings themselves might be. That is, we have all recognized that we would probably expect to find lower properties in certain sections of castings than we would find in the test lugs when separately or integrally cast. A report, therefore, was prepared as a result of the examination of a number of castings made by a number of manufacturers.

The work was done on alloy castings of two different types: One of those types is the common molybdenum steel casting. The other type I prefer not to mention because it might indicate the manufacturer involved. For the molybdenum steel castings, we called for physical properties of

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[2] Professor of Metallurgical Engineering and Director of Department of Engineering Research, University of Michigan, Ann Arbor, Mich.

NOTE: This report was presented at a session on Steel Founding at the 1936 Convention of A.F.A. in Detroit, Mich.

70,000 lb. per sq. in. tensile; 50,000 lb. per sq. in. yield; 25 per cent elongation; 35 per cent reduction of area and a minimum impact value of 25 ft.-lb. The other type of casting had higher physical properties than those mentioned.

We tested separately and integrally cast sections, and then sections from various parts of the valve bodies. For the purpose of getting some basis of comparison from the products made by these various concerns, we arbitrarily assumed that the physical properties were acceptable where they met all of the given physical properties.

That was rather a hard and fast separation because, if we were calling for 50,000 lb. per sq. in. yield point and we found 48,000 lb. per sq. in., that would throw that particular test bar out as unacceptable. Of course, in commercial practice if any reasonable inspector saw a difference of that much he would accept the casting.

Recognizing that many of these test bars were taken from the bodies of the castings and that those test bars would doubtlessly not be, as a rule, of the same quality that we found in the separately or the integrally cast bars, we ran into this condition: That, with regard to one manufacturer, 40 per cent of the castings examined were acceptable; for another manufacturer, 61.1 per cent; another, 43.7 per cent; and another 0 per cent. That is on the basis of the tensile properties.

On the basis of the impact properties, we found from one manufacturer 37.5 per cent of the specimens examined met the requirements; from another, 88.7 per cent; from another, 23.3 per cent; from another, 30.6 per cent.

We found, on separately cast bars one manufacturer showed a tensile strength of 88,900 lb. per sq. in.; another 82,950 lb. per sq. in.; another 82,100 lb. per sq. in.; another 71,000 lb. per sq. in.; another 79,000 lb. per sq. in. On integrally cast bars, they ran about the same, showing very acceptable properties as a rule on both separately and integrally cast bars.

Here is the practice of one manufacturer on longitudinal sections taken from the cope welding end. It showed 81,000 lb. per sq. in. tensile, 48,900 lb. per sq. in. yield, 20.7 per cent elongation, and 34.1 per cent reduction. The same tests taken from the drag section, instead of the cope, showed a tensile strength of 83,000 lb. per sq. in., 52,500 lb. per sq. in. yield, 21.8 per cent elongation, and 39.4 per cent reduction.

Some values taken from some of the other products in a radius section cope side are as follows: 77,850 lb. per sq. in. tensile, 50,750 lb. per sq. in. yield, 15.5 per cent elongation, and 24.4 per cent reduction of area. We found no outstanding continuity with regard to the fact that if, let us say, the drag side of the welding section of one manufacturer's product was poor in the one case, it was poor in the other cases.

With regard to the impact values, we found those from one manufacturer, averaged, on separately cast bars, 25.3 ft.-lb.; another manufacturer, 40.5 ft.-lb.; another, 25.5 ft.-lb.; another, 27.5 ft.-lb. In the case of the integrally cast bars, we found one manufacturer averaged 40.7 ft.-lb.; another, 61.0 ft.-lb.; and another, 25.8 ft.-lb.

When the impact specimens were taken from the body of the casting, results ranged anywhere from, say, 13 up to 53 ft.-lb. as the high value, with most of them in the range of from 20 to 30 ft.-lb.

These castings were also examined microscopically. We found one manufacturer who submitted sections that contained blow holes and cracks.

To sum up, this study was primarily undertaken for the purpose of determining the extent to which one could depend upon the physical properties in the casting proper on the basis of the physical properties obtained from either separately or integrally cast bars.

As to the general conclusions with regard to the question of whether the lugs should be separately or integrally cast, I will say for the most part that it does not make any outstanding difference whether they are cast separately or integrally, providing judgment is used in the spacing of the test bar sections. Of course, results do show a falling off in the physical properties when the sections are taken from the casting proper. We all recognize at this time, in this stage of the art, that we can not expect to get the highest possible physical properties in all sections. The ideal we should all work toward is a condition whereby the properties taken from any portion of the casting will correspond with those taken from either separately or integraly cast test sections.

CHAIRMAN R. A. BULL[3]: Dr. White, may I ask whether, in the case of the specimens you tested, the manufacturer applied heat treatment according to his own preferred practice, or were the castings heat treated according to a prescribed method?

DR. WHITE: I would say in all cases the manufacturer heat treated these castings in accordance with such method as he wished to use. In one or two cases, they consulted with us with regard to the method of heat treatment which they thought should be used, but the responsibility for them to adopt such heat treatment was theirs. We merely used the physical properties which were set forth as a yardstick.

P. E. MCKINNEY[4]: I think Dr. White's discussion is very interesting. It leads, though, to one question, that the proposition of comparing the physical properties of coupons taken from test bars and from the body of castings must always be tied-up very closely with the method of treatment. There has been some variations in properties. I assume results were all based on carbon-molybdenum steel as between different manufacturers.

Generally speaking, it has been our observation that the nearer you get to a full annealed casting, the more closely will the tensile and yield point values, on either separately or integrally cast bars, compare with the results obtained from body sections of the casting. Values obtained from the body section specimen may not be as high as those from the coupons, which would naturally be expected with the same composition. But if you try to combine a close comparison between the body of the casting and the coupon with regard to heat treatment, I think we will get some very misleading figures.

That also comes into play in impact. Our methods in considering impact in separate, notch-bar, impact tests necessitates treatments which defeat uniformity between the coupon and body of the casting. One point that should be borne in mind when making this study is that invariably we must have the heat treatment that is given and the physical properties

[3] Consultant on Steel Castings, Chicago, Ill.
[4] Metallurgical Engineer, Bethlehem Steel Co., Bethlehem, Pa.

that are prescribed rather than to just discuss some generalities, whether we are or are not meeting the expected comparative figures between coupons and center sections.

I would like to ask whether Prof. White or Mr. Sampson have observed up to now any ratio between the tensile properties and yield that might be expected as between coupons and body bars on full-annealed castings of carbon steel or of some other alloys?

MR. SAMPSON: The data we have so far are rather limited and in divulging them, that fact should be borne in mind.

It so happens that the data we have are all on plain carbon steel, given a full anneal at from 800 to 900° C. (1472 to 1652° F.). In general, the tensile strength and yield point of the test pieces, whether from separately or integrally cast coupons, show slightly higher than the body of the casting that was tested. The differences were more noticeable in the case of elongation and reduction of area. Results were obtained on both acid open-hearth and basic electric steels. There was little difference between the two.

The average differences in tensile, yield, elongation and reduction of area are as follows:

Tensile Strength:	2.25 per cent less in tests cut from castings.
Yield Point:	1.2 per cent higher in tests cut from castings.
Elongation:	9.2 per cent less in tests cut from castings.
Reduction of Area:	4.8 per cent less in tests cut from castings.

CHAIRMAN BULL: Do I understand that you got as much as 90 per cent of the ductility from the specimens taken from the body of the castings, compared to the ductility manifested by test coupons made in the conventional way?

MR. SAMPSON: That is true; the data we have so far is not clear as to the design of the casting, location of risers and gates, location of tests taken from castings, etc., and I feel the data could be misleading. There would be considerable difference, I believe, in tests taken from different sections of many castings.

CHAIRMAN BULL: Depending on the location of the coupon, you may get a very satisfactory result. In this case, Mr. Sampson, were specimens taken from various portions of the body of the casting?

MR. SAMPSON: Yes. The data we had in many cases was insufficiently clear as to where the test piece came from and I feel that results could be misleading.

H. D. PHILLIPS[5]: On the question of cutting test bars from castings, particularly alloy castings, we have had some experience. We have one specification which we have to meet whereby the customer calls upon us to cut a test bar from the mutually-agreed worst spot in the casting. This particular casting has quite a change in mass. It is a header, used by oil refineries. Before we undertook to produce this order, we did quite a bit of work to see just what properties we would get from this casting.

[5] Dodge Steel Co., Philadelphia, Pa.

We cut test bars from 15 or 20 different spots in that casting, and by heat treating that steel to give us the best properties in the separately cast test bar, we got properties in the neighborhood of 80,000 lb. per sq. in. yield, 108,000 lb. per sq. in. tensile, 21 per cent elongation and 54 to 55 per cent reduction of area value, cold bend, 180°, bent flat on itself. Incidentally, we got a Brinell of 220 on that test bar. By heat treating that casting, we got a Brinell in the tube section of 175, in the body section 228, and in the plug seat section about 175. It varied all over the casting that way, and we got the worst Brinell properties under the head.

We made the casting in line with Mr. Batty's advocated 180° reversal method. Under the head of the casting, we got about 85,000 lb. per sq. in. tensile, and only about 17 per cent elongation and about 35 or 36 per cent reduction of area.

CHAIRMAN BULL: As compared with something like 50 per cent reduction?

MR. PHILLIPS: 54 per cent in the rest of the casting. Of course, we had to use external chills on this job and particularly in this one spot where we got about 65,000 lb. per sq. in. yield, 90,000 lb. per sq. in. tensile, and I think it was 24 or 25 per cent elongation and 66 per cent reduction of area. That happened to be the mutually agreed worst spot in the casting. However, we failed to meet their specifications because we did not meet the tensile strength. To meet their specifications, we had to give the casting a full anneal. In other words, we had to run both carbon and chrome higher and give a full anneal, and be sure the temperature drop in the furnace was not over 50° F. per hour to avoid any air hardening.

Out of the rest of the casting, taking 15 or 20 bars—we took every possible section—we got excellent properties. I would say, on the average, the properties ran 175 Brinell, in the neighborhood of 60,000 or 65,000 lb. per sq. in. yield, 95,000 lb. per sq. in. tensile, 24 per cent elongation and 58 per cent reduction of area.

In the body part of the casting, we developed 85,000 and 90,000 lb. per sq. in. yield, 115,000 lb. per sq. in. tensile, 18 to 20 per cent elongation and 45 to 50 per cent reduction of area.

In other words, by making a thorough study of the casting, we were able to get some excellent results but failed to meet the expectations. That necessitated a change in chemical specifications. They held us to a carbon maximum and we had to ask for a revision. That is what I would like to bring out, in considering test bars cut from castings, we must consider the influence of mass and the possible changes we have to make in the heat treatment they want and the physical and chemical specifications they impose upon us.

On that same casting, taking other castings of different composition, we found we had delved into a very interesting subject and have gathered quite a bit of information on steels for high impact value at low temperatures, 50 or 75 degrees below zero F. With the medium-manganese-molybdenum steels, and others, we found it to be pretty much the case that to get any uniformity, we have to resort to a full anneal. In that case we fail to develop the best physical properties of which the steel is capable.

By normalizing and drawing, we do develop the properties of the steel nearer to its fullest extent.

C. E. SIMS[6]: I want to make a plea for reasonableness and common sense in that matter of relation between test bars and castings. The question immediately arises, does the test bar represent the casting? I say no. It only represents the steel that is going into the casting, and the sooner we realize that, the better. The test bar is made under ideal conditions, or it should be. Any sensible foundryman will make it under as nearly ideal conditions as he can to get the maximum physical properties. The various parts of the casting can by no stretch of the imagination be made under ideal conditions for density and solidity.

In compiling some data some time ago with regard to separately cast test bars and test bars cast integrally with castings, I found the average results on the bars integrally cast are actually better than the ones separately cast. That meant the bars that had a very good chance to become solid were placed in favorable locations where they could get the proper feeding. The only advantage in an integrally cast test bar is that it also represents to some extent the heat treatment the casting has received. Take an example of a ¾-in. section, cast either vertically or horizontally, and I know of no means by which you can avoid a little line of shrinkage and lower density down the center of that section. You could put on a riser and it would still have secondary piping down in that casting. Now, if you cut a test bar from that section, you cut your test bar out of the very worst metal in that section and it is going to fall down miserably. On both surfaces of that casting you have sound metal, as good as the test bar. This line of shrinkage down the center is the neutral axis and has very little relation to the serviceability of the casting. However, if you have a large section to cut a casting from and you cut it from the drag side, it is equivalent to an integrally cast test bar and will give good results.

MR. PHILLIPS: There is one point in the cutting of test bars from castings where the manufacturers seem to be taking a bit of advantage of us. For instance, we are allowed to machine a bar down to 0.505-in. diameter, say, whereas, in a lot of cases when you cut a test bar from a casting, the customer insists on the rough cast surface being retained wherever possible. I know of one case where they pulled the bar actually one inch square, the metal section at that point happened to be one inch, and as a result there were two surfaces cast. The metal surface was imperfect and it naturally influenced the quality of that test bar.

[6] Battelle Memorial Institute, Columbus, O.

Deformation and Resilience of Molding Sand

By H. W. Dietert* and R. A. Dietert**, Detroit, Mich.

Abstract

The authors have studied two properties of molding sand that heretofore have received but little attention, namely, deformation and resilience. It is pointed out that the ease with which a sand deforms is of vital interest especially where inaccurate mold partings occur and that it is an important factor when the flask is lifted. Resilience of molding sand is a good indication of the strength of the sand and especially of its resistance to shock loads. The authors conducted a series of investigations and have determined the effect of variations in moisture, grain size, clay content, mold hardness and sea coal on these properties. In this paper, they give the results of their investigations and find that deformation increases as the moisture increases, as the sand becomes finer, as the clay content is high or low, as the mold hardness increases, and as the sea coal content increases. They also found that sand resilience is increased by increasing moisture content, fine material, clay content, mold hardness and sea coal content.

1. Molding sand, like other engineering materials, deforms, that is, changes its shape slightly when an operating load is imposed upon it. The amount of change in shape is very small for such loads as one lb. per sq. in., but of considerable amount as the load increases to the higher operating loads.

Deformation

2. The property of a molding sand which causes the sand to change its shape when a load is applied is called deformation. Deformation of molding sand is expressed in thousandths of an in. per in. that the A.F.A. standard test specimen[1] changes in length at rupture load.

3. The deformation property of molding sand plays an im-

* ** President and Chemical Engineer, respectively, H. W. Dietert Co.

[1] *"Testing and Grading Foundry Sands, Standards and Tentative Standards,"* A.F.A., pp. 34-35, 61 (1931).

Note: This paper was presented at a session on Sand Research at the 1936 Convention of A.F.A. in Detroit, Mich.

portant part in the stripping of the molds where inaccuracies of draft are present. It also prevents drops as the flask distorts when it is lifted. The deformation of the sand gives flexibility to the sand at parting of mold to take up inaccuracy of mold at the part and also in being able to deform sufficiently to receive considerable core print pressure without failure.

4. The deformation of molding sand plays an unfavorable part in that it allows the molten metal to swell the mold. It also has the tendency to open up the mold at parting, thus causing bleeders. However, the failure of the molding sand to possess sufficient deformation causes the sand to be "short," that is, to feel brittle and easily broken upon shock or distortion.

Modulus of Resilience

5. The modulus of resilience of a sand may be defined as an index of work that is required to break the sand specimen; it combines the deformation and compression strength. With this in view, it is a good index of the strength of a material, particularly so with reference to shock loads and finds excellent application in the control of molding sand strength.

6. The modulus of resilience factor, as used in this investigation, will be slightly altered so that it can be easily applied to sand control. The term "sand resilience" will be used to express the resilience factor, combining compression strength with deformation at rupture. The unit being work required to break the A.F.A. standard test specimen times 2,000. Sand resilience is calculated by multiplying the compression strength, per sq. in., by deformation $\times$ 1,000 at rupture load. This simplification is used to reduce the effort required in calculations and also to record a larger figure.

Sand Resilience = Compression $\times$ Deformation $\times$ 1,000

7. The strength of a molding sand does not fully measure its ability to perform satisfactorily under load any more than does, for example, the strength fully measure the load performance of malleable iron. The property of ductility or deformation should be included with the strength data to obtain a complete index of load performance. In the testing of molding sand for its load performance it is desirable to express the bond strength as sand resilience.

8. This discussion will show how the deformation of molding

sand and sand resilience under compression loads varies as each sand property is changed, such as, moisture, grain size, clay content, mold hardness and sea coal content, in an endeavor to submit information which will prove valuable in the control of molding sand.

APPLICATION OF DEFORMATION IN THE FOUNDRY

9. Sufficient deformation of molding sand allows pattern plates to be so constructed that as much as 1/32-in. green sand crush may be carried at parting line. Upon clamping such molds where dry sand crush of 1/64-in. may also be carried, the usual fins at parting line are eliminated, thus reducing the cost of dressing the casting.

10. When the crush of a core print or parting exceeds the safe limit of the sand, a crush defect is the result. The remedy is to increase deformation or reduce the crush of the mold.

11. The possibility of the mold parting to open up due to ferrostatic pressure increases as the deformation of a sand increases. This is due to the fact that a sand with high deformation changes shape easily under load. A casting may be lost due to iron bleeding through parting line. Such losses may be more numerous when the deformation is high at a relatively small load.

12. The ability of a sand to deform does not always lead to casting defects. Inaccurate pattern or core equipment may place a high crushing load on the mold where core print strikes. Sands possessing high deformation will take more crush without failure than sand with low deformation. Where crush defects are experienced, the sand may be partly at fault when it possesses a low deformation. The remedy is either an increase of deformation of the sand or correction of pattern equipment by reducing the amount of the crush.

RELATION OF DEFORMATION TO THE PHYSICAL PROPERTIES OF MOLDING SAND

13. The deformation of molding sand may be best studied by determining how each property of molding sand affects it. Both synthetic and natural sands were used in this investigation and only one physical property was changed at a time.

Method of Measuring Deformation

14. The deformation of a molding sand when subjected to a

compression load may be readily determined by measuring the decrease in length of the A.F.A. standard test specimen (2 x 2 in.) as the compression load is increased up to rupture load.

15. The compression instrument, Fig. 1, may be used for this test by counting the number of turns of lever required to break the specimen. The deformation of the sand may be computed by the formula:

$$\text{Deformation} = \frac{\text{Turns of Spindle Lever}}{\text{No. of Threads on Spindle per In.}} - \frac{\text{Lb. Reading}}{\text{No. of Lb. Graduation per In.}}$$

16. The strength machine may be equipped with an indicating deformation tester, as illustrated in Fig. 2. The deformation of the sand is read on the dial of the deformation tester without

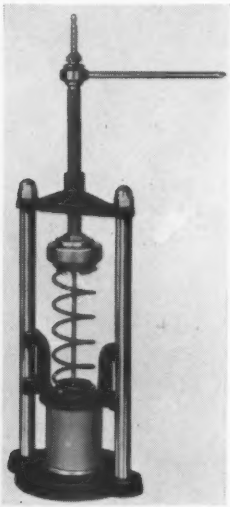

FIG. 1—INSTRUMENT FOR DETERMINING COMPRESSIVE STRENGTH OF MOLDING SAND.

increasing the time required to make the compression strength test. The yield load may be noted by sudden increase in movement of the indicator hand.

17. A detailed study of deformation may best be made when an autographic deformation tester, illustrated in Fig. 3, is at-

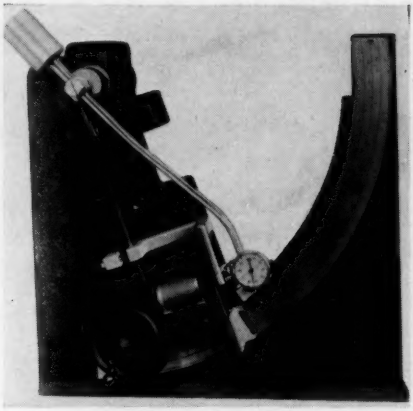

FIG. 2 — STRENGTH TESTING MACHINE EQUIPPED WITH DIAL FOR INDICATING DEFORMATION.

tached to the strength machine. With this equipment a graphic deformation curve is recorded on a piece of paper showing the deformation in thousandths of an in. per in. of sand specimen length and the load in lb. per sq. in. A diagram of this nature is called a "stress-strain" diagram. Both the indicating and autographic methods were used in this investigation.

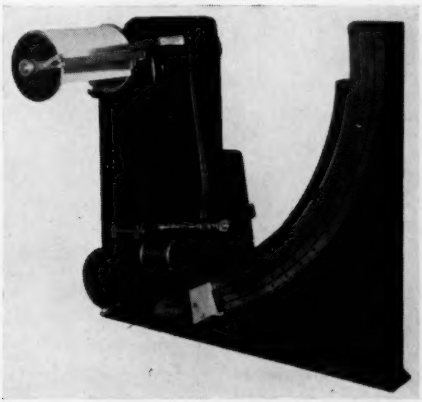

FIG. 3—SAME TYPE MACHINE AS IN FIG. 2 BUT EQUIPPED WITH AN AUTOGRAPHIC RECORDING MECHANISM.

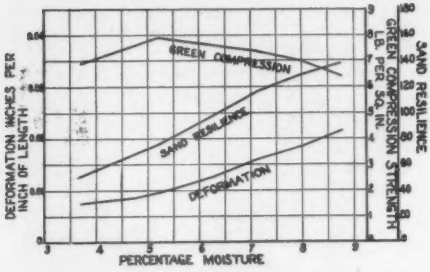

FIG. 4—EFFECT OF MOISTURE ON THE DEFORMATION OF A NATURAL OHIO PRODUCTION PLATE-MOLDING SAND.

Table 1

DEFORMATION VS. MOISTURE

Per Cent Moisture	Green Compression, lb. per sq. in.	Deformation, in. per in.	Sand Resilience
3.7	6.9	0.0075	51.7
4.8	7.65	0.0082	62.7
5.2	7.9	0.0095	75.0
6.2	7.65	0.0125	95.6
7.1	7.4	0.016	118.4
8.0	7.0	0.0185	129.5
8.8	6.45	0.0217	139.9

DEFORMATION AS AFFECTED BY MOISTURE

18. In sand control, moisture is recognized as a most important item to be accurately controlled within narrow limits. This investigation adds to the importance of moisture control in that it shows that the deformation of a sand increases rapidly as moisture content increases.

19. This is well illustrated in Fig. 4 and Table 1 where the deformation versus moisture content is shown for a natural, plate-production sand used on a jolt-squeeze molding machine. The test figures of this sand are: green permeability, 19, and green compression, 7.0 lb. at a temper of 7 per cent moisture. The deformation of the sand at 3.5 per cent moisture is 0.007 in. per in. and 0.022 in. per in. or three times as great at 9 per cent moisture. The small deformation of the sand at low moisture content explains the brittleness of dry tempered sand which one may feel by hand. It also explains the tendency toward increase in drops and crushes when the sand is low in moisture. The large

deformation for the sand containing high moisture explains why drops and crushes decrease and the tendency to swell increases as moisture content is carried high in a molding sand.

20. A graphic illustration of the behavior of sand under load, tempered to different moisture contents, is shown by the stress-strain diagram, Fig. 5. The autographic stress-strain diagrams shown in Fig. 5 reveal not only the maximum deformation at rupture load but also the deformation of the sand at any load below rupture. The vertical axis of the diagrams represents the load while the horizontal axis represents the deformation where each 1/8 in. equals 0.001 in. per in. deformation.

21. The stress-strain diagrams of Fig. 5 were obtained from natural-bonded, jolt-squeeze molding machine production molding sand. This sand was tempered to 5.7, 6.8 and 8.8 per cent moisture. A comparison of the three diagrams shows that as the amount of moisture increases, the rate of deformation increases rapidly even at very small loads.

22. It is of particular interest to note that the strain is proportional to the stress (Hooke's law), since the diagram is a straight line for a certain distance. At the point where the diagram departs from a straight line, the yield load is reached. The yield load for the sand tempered to 5.7 per cent moisture is 6.4 lb. per sq. in., 5.8 lb. per sq. in. when tempered to 6.8 per cent and 4.4 lb. per sq. in. when tempered to 8.8 per cent moisture. Some maintain that the yield load is a better index of the safe load that a material will carry than using the ultimate load and a factor of safety. The yield load is a fairly constant portion of the ultimate strength of the sand when tempered to different moisture contents.

23. The deformation at yield load for the sand does not vary

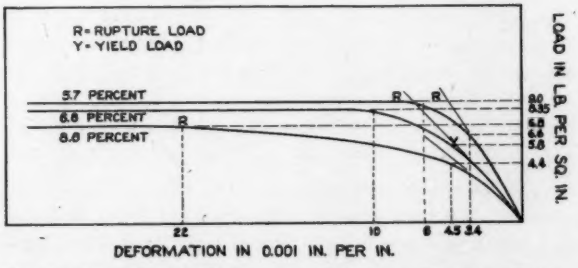

FIG. 5—STRESS-STRAIN DIAGRAM FOR VARIOUSLY TEMPERED SANDS.

as greatly as does the deformation at rupture load as moisture is changed in a sand, see Fig. 5, compare points *R* with *Y*. The modulus of compression of the sand tempered to the different moistures gives a strength index, *i.e.*, yield load divided by deformation at yield load. For example, at 5.7 per cent moisture the modulus of compression equals 1676, at 6.8 per cent it is 1288 and at 8.8 per cent it is 977. The green compression strengths are: 9 lb. per sq. in. at 5.7 per cent, 8.35 lb. per sq. in. at 6.8 per cent and 6.85 lb. per sq. in. at 8.8 per cent.

24. The sand resilience for 5.7 per cent moisture is 54, for 6.8 per cent moisture it is 83.4 and for 8.8 per cent moisture it is 149.8. This factor indicates that the sand possesses considerable greater strength as moisture increases from 5.7 to 8.8 per cent moisture, which is not in agreement with compression strength.

Table 2

DATA FROM STRESS-STRAIN DIAGRAM, FIG. 5, COVERING CHANGE IN MOISTURE CONTENT

Moisture, Per Cent	5.7	6.8	8.8	Increase
Compression, lb. per sq. in.	9.0	8.35	6.85	..
Yield Load, lb. per sq. in.	6.4	5.8	4.4	..
Modulus of Compression, lb. per per sq. in.	1676	1288	977	..
Sand Resilience	54.0	83.4	149.8	2.7
Deformation *R*, in. per in.	0.006	0.010	0.022	..
Deformation *Y*, in. per in.	0.0034	0.0045	0.0045	..

25. Table 2 shows data obtained from the stress-strain diagram, Fig. 5. A comparison of the 5.7 and 8.8 per cent moisture figures shows that the modulus of compression for the 8.8 per cent sand is 40 per cent weaker while by the compression test it is only 25 per cent weaker. When the sand resilience is used as an index it may be noted that 8.8 per cent tempered sand is 2.7 greater in strength as measured by the sand resilience than the 5.7 per cent tempered sand. Judging from foundry practice, the sand resilience factor is correct.

26. Assume that the interior of a mold is subjected to ferrostatic pressure of 24 in. of molten cast iron head or 6 lb. per sq. in. pressure. From the stress-strain diagram, Fig. 5, the molding sand on the surface of the mold, when tempered to 5.7 per cent moisture, will swell 0.003 in. per in., at 6.8 per cent it will swell 0.006 in. per in. and at 8.8 per cent it will swell 0.0085 in. per in., pro-

viding the molds are all rammed with equal energy as in the A.F.A. standard test specimen.

27. The above indicates that the castings weight will increase as percentage of moisture increases. The above will hold true only where sand is mixed with muller type of mixer. Other types of mixers will cause the sand to have lower strength at low moisture than at temper, thus greatly affecting the deformation.

DEFORMATION AS AFFECTED BY GRAIN SIZE

28. The deformation of molding sand is little affected by the size of the sand grains, as shown in Table 3 and Fig. 6. The deformation is shown for an Illinois clay bonded synthetic sand consisting of sand grains of single meshes. Sufficient bond was added to each sand to secure 5.0 lb. per sq. in. green compression when tempered to best workable moisture content. The deformation of

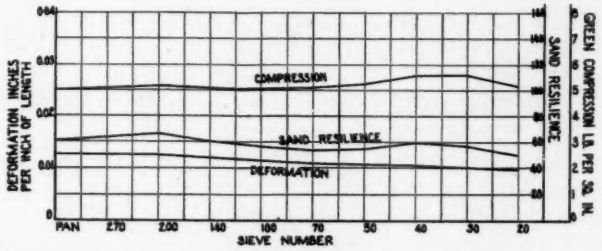

FIG. 6—EFFECT OF GRAIN SIZE ON DEFORMATION. VARIOUS SIZES BONDED TO 5 LB. PER SQ. IN. COMPRESSION STRENGTH WITH ILLINOIS CLAY.

Table 3

DEFORMATION VS. FINENESS

Mesh Size	Green Compression, lb. per sq. in.	Deformation, in. per in.	Sand Resilience
12-20	5.3	0.0095	50.3
20-30	5.7	0.010	57.0
30-40	5.7	0.0105	59.8
40-50	5.2	0.0105	54.6
50-70	5.06	0.0107	54.1
70-100	5.0	0.0113	56.5
100-140	5.03	0.012	60.3
140-200	5.3	0.0125	66.2
200-270	5.0	0.0125	62.5
270-Pan	4.9	0.0125	61.2

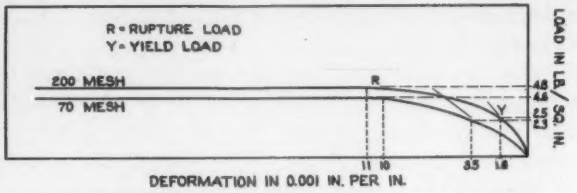

FIG. 7—STRESS-STRAIN DIAGRAM FOR 200 AND 70 MESH SAND.

Table 4

DATA FROM STRESS-STRAIN DIAGRAM, FIG. 7, COVERING CHANGE IN FINENESS

Mesh	70	200	Increase
Compression, lb. per sq. in.	4.8	4.5	..
Yield Load, lb. per sq. in.	2.5	2.3	..
Modulus of Compression, lb. per sq. in.	714	1279	1.78
Sand Resilience	46.0	52.8	1.1
Deformation *R*, in. per in.	0.010	0.011	1.1
Deformation *Y*, in. per in.	0.0035	0.0016	..

a sand composed of pan material is 0.012 in. per in. and 0.010 in. per in. for 20 mesh sand.

29. The stress-strain diagrams are shown in Fig. 7 for this same type of sand consisting of 70 and 200 mesh size. A study of the diagrams will show that the yield load and also the deformation at rupture load is in close agreement for these two widely different sized sands. The deformation at yield load is quite different in that the 200 mesh sand has a deformation of 0.0016 in. per in. at yield load and the 70 mesh sand deforms 0.0035 in. per in., which is practically double the amount. This would indicate that a coarse sand must be rammed harder to avoid swelling. This is further exemplified by the modulus of compression of the 70 mesh sand, which is 714, while the 200 mesh sand has a modulus of compression of 1279.

30. The data shown in Table 4 is of particular interest inasmuch as it shows that the sand resilience of the 200 mesh sand is 1.78 greater than the 70 mesh sand. The modulus of compression and deformation at rupture shows 1.1 per cent increase, while all other data show a decrease. The 200 mesh sand, though of lower compression strength, will withstand greater abuse in the foundry with reference to loading, as indicated by its greater sand resilience.

DEFORMATION AS AFFECTED BY PERCENTAGE CLAY

31. The quantity of clay substance contained in a molding sand affects all known physical properties of the sand. It is known that up to a certain percentage of clay substance, the clay can be carried on the surface of the sand grains, while with higher percentages the clay acts as a filler between the sand grains.

32. The deformation property of a sand indicates this excess percentage of clay. Referring to Table 5 and Fig. 8, where de-

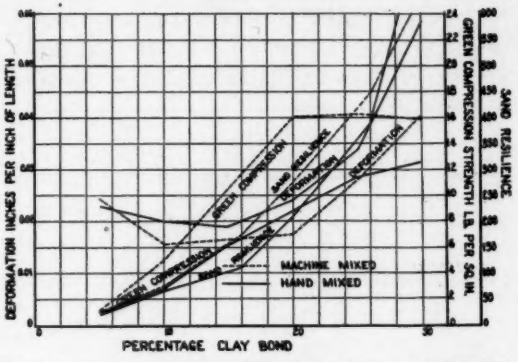

FIG. 8—EFFECT OF CLAY CONTENT ON THE DEFORMATION OF OHIO CLAY BONDED OHIO SILICA SAND.

Table 5

DEFORMATION VS. PER CENT CLAY

Hand Mixed

Per Cent Clay	Green Compression, lb. per sq. in.	Deformation, in. per in.	Sand Resilience
5	1.0	0.023	23.0
10	2.9	0.020	58.0
15	6.2	0.019	117.8
20	8.9	0.024	213.6
25	11.5	0.034	391.0
30	12.7	0.063	800.0
	Muller Mixed		
5	1.2	0.0245	29.4
10	5.0	0.0157	78.5
15	10.7	0.0165	176.5
20	16.1	0.0175	281.7
25	16.2	0.028	453.6
30	15.9	0.0405	643.9

formation change is shown with change of percentage clay substance, the sand used was synthetic sand prepared from an Ohio silica sand and an Ohio clay bond. It may be noted that deformation is the lowest when clay content for this particular sand is 15 per cent. The deformation increases as clay content increases or decreases from this quantity of clay. The greatest increase in deformation occurs as clay content increases beyond 15 per cent. This is undoubtedly due to the fact that clay is acting as a filler and the sand acquires a clay-like property.

33. The data in Table 5 or curves in Fig. 8 show that the deformation of a muller mixed sand is less than that of a hand mixed sand. Under these conditions, the muller mixed sand should

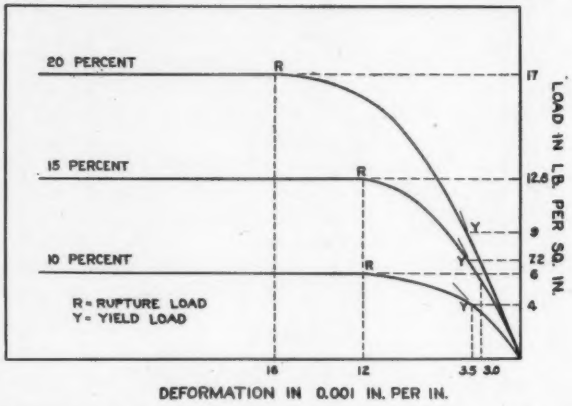

FIG. 9—STRESS-STRAIN DIAGRAM FOR 10, 15 AND 20 PER CENT CLAY BONDED SAND.

show less loss due to bleeders and swells than the hand mixed sands.

34. Within the range of green compression strength as used in the foundry, namely, 4.5 to 9 lb. per sq. in., the deformation has a tendency to increase as the strength decreases, explaining the fact that swells may be caused by weak sand.

35. The stress-strain diagrams, Fig. 9, illustrate the rate of deformation as the load increases up to the rupture load. An increase of clay content tends to straighten the first part of the diagram, indicating that the modulus of compression of the sand increases with an increase of clay. The moduli of compression are 3000 at 20 per cent clay, 2181 at 15 per cent clay and 1331 at 10 per cent clay. Compression strengths are, respectively, 17.0, 12.85

Table 6

DATA FROM STRESS-STRAIN DIAGRAM, FIG. 8, COVERING CHANGE IN CLAY CONTENT

Clay, per cent	10	15	20	Increase
Compression, lb. per sq. in.	6.0	12.8	17.0	2.83
Yield Load, lb. per sq. in.	4.0	7.2	9.0	2.25
Modulus of Compression, lb. per sq. in.	1331	2181	3000	2.25
Sand Resilience	72.0	153.6	272	3.77
Deformation *R*, in. per in.	.012	.012	.016	1.33
Deformation *Y*, in. per in.	0.0035	0.003	0.0035	..

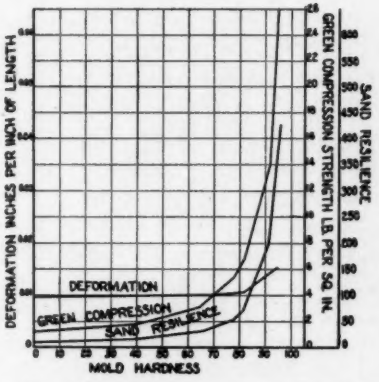

FIG. 10—EFFECT OF MOLD HARDNESS ON THE DEFORMATION OF NATURAL ILLINOIS PRODUCTION MOLDING SAND.

Table 7

DEFORMATION VS. MOLD HARDNESS

No. of Rams	Hardness	Green Compression, lb. per sq. in.	Deformation, in. per in.	Sand Resilience
¼	0	1.2	0.0095	11.4
½	41	1.9	0.0100	19.0
1	65	3.3	0.0100	33.0
2	78	5.3	0.0105	55.6
3	82	6.8	0.0105	71.4
9	92	14.1	0.0145	204.4
18	95	26.0	0.0165	429.0

and 6 lb. per sq. in. The sand resilience for the 10 per cent clay bonded sand is 72, for the 15 per cent clay it is 152 and 272 for the 20 per cent clay bonded sand.

36. Referring to Table 6 and noting the column showing increase, it is of interest to note that all factors show an increase as clay content increases with the exception of deformation at yield load. The sand resilience shows the greatest increase of 3.77 for a clay increase from 10 to 20 per cent while compression strength shows 2.83.

DEFORMATION AS AFFECTED BY MOLD HARDNESS

37. The greatest tool that a molder possesses to obtain a desired mold condition is mold hardness. Mold hardness materially affects all properties of a sand, such as, permeability, green and dry strength, expansion and deformation. The manner in which mold hardness affects deformation is shown in Table 7 and Fig. 10. It may be noted that deformation increases slowly as the mold hardness increases up to 82. As mold hardness increases beyond this point, the deformation increases quickly. This is probably accounted for by the unusually rapid increase of green compression strength as the sand is rammed to an extreme high mold hardness.

38. The stress-strain diagram for sand rammed to a mold

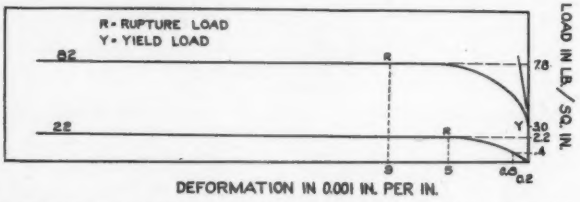

FIG. 11—STRESS-STRAIN DIAGRAM FOR SAND RAMMED TO MOLD HARDNESS OF 22 AND 82.

Table 8.

DATA FROM STRESS-STRAIN DIAGRAM, FIG. 11, COVERING CHANGE IN MOLD HARDNESS

Mold Hardness	22	82	Increase
Compression, lb. per sq. in.	2.2	7.8	3.5
Yield Load, lb. per sq. in.	0.4	3.0	7.5
Modulus of Compression, lb. per sq. in.	500	1500	3.0
Sand Resilience	11.0	70.2	6.3
Deformation *R*, in. per in.	0.005	0.009	1.8
Deformation *Y*, in. per in.	0.002	0.008	..

Table 9

DEFORMATION VS. SEA COAL

Per Cent Sea Coal	Green Compression, lb. per sq. in.	Deformation, in. per in.	Sand Resilience
0	5.5	0.0105	57.7
2	6.3	0.0140	88.2
4	6.9	0.0165	113.8
6	7.8	0.0195	152.1
8	8.8	0.0170	149.6
10	9.5	0.0155	146.7
12	10.7	0.0135	144.4

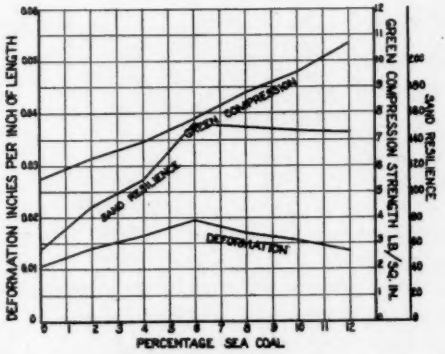

FIG. 12—EFFECT OF SEA COAL ON THE DEFORMATION OF ILLINOIS CLAY BONDED SMITH JUNCTION LAKE SAND.

hardness of 22 and 82 is illustrated in Fig. 11 and data tabulated in Table 8. Rupture loads of 2.2 and 7.8 lb. were obtained respectively, which shows an increase in strength of 3.5 times. The yield loads are respectively, 0.4 and 3.0 lb. per sq. in., which shows an increase of 7.5 times. The moduli of compression for the sand rammed to 22 mold hardness is 500 and 1500 for the 82 mold hardness, an increase of 3.0 times. The sand resilience indicates that the sand is 6.3 stronger when rammed to 82 than when rammed to 22 mold hardness.

DEFORMATION AS AFFECTED BY SEA COAL

39. Sea coal addition to molding sand forms one of the most effective means of improving the finish on gray iron castings. Sea

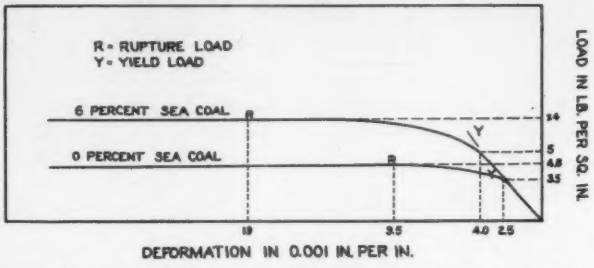

FIG. 13—STRESS-STRAIN DIAGRAM FOR SAND CONTAINING 0 AND 6 PER CENT SEA COAL.

Table 10

DATA FROM STRESS-STRAIN DIAGRAM, FIG. 13, COVERING CHANGE IN SEA COAL CONTENT

Sea Coal	0	6	Increase
Compression, lb. per sq. in.	4.8	7.4	1.54
Yield Load, lb. per sq. in.	3.5	5.0	..
Modulus of Compression, lb. per sq. in.	1250	1250	..
Sand Resilience	45.6	140.6	3.0
Deformation *R*, in. per in.	0.0025	0.004	1.6
Deformation *Y*, in. per in.	0.0095	0.019	2

coal is an entirely foreign material in molding sand and its effect on the sand properties are of particular interest.

40. The manner in which sea coal affects the deformation of a synthetic molding sand composed of Michigan lake sand and Illinois clay may be studied by observing data tabulated in Table 9 or shown graphically in Fig. 12. The deformation and strength of the sand increases as sea coal is added up to 6 per cent. A further increase in sea coal reduces the deformation, undoubtedly due to the fact that small quantities of sea coal do not fill the pores of the sand completely but when more than 6 per cent addition is made, the sand grains are held apart by the sea coal which produces a sand of lower deformation. The quantity of sea coal required to reach the inversion point will probably vary for different sands.

41. The stress-strain diagrams of molding sands containing no sea coal and 6 per cent sea coal are shown in Fig. 13 with data shown in Table 10. The sand with 6 per cent sea coal has a yield load of 5.0 lb. per sq. in. and the sand without sea coal has a yield load of 3.5 lb. per sq. in. The slope of the diagrams are identical

since both sands have a modulus of compression of 1250, indicating that sea coal does not affect swells. The sand resilience values place the strength increase at 3.0 times, due to the addition of 6 per cent sea coal. After the sand has been burnt the ash of the sea coal will reduce the strength of the sand.

METHOD OF CONTROLLING DEFORMATION

42. The deformation of molding sand in the foundry may be controlled most effectively by controlling the moisture of the sand since deformation changes more as moisture is changed than for any other known change of the sand. A decrease of moisture will decrease deformation and increase modulus of compression.

43. A change in the fineness of molding sand will not materially change the deformation. A decrease of fines will decrease the deformation. The modulus of compression is increased as fineness increases, and this is a desirable condition.

44. The mold hardness may be changed to secure a change in deformation. For example, deformation may be reduced by reducing the mold hardness.

45. The use of an excess or an insufficient amount of clay bond will result in a high deformation. It should be remembered that modulus of compression increases as clay content increases. The selection of raw bonding materials, with reference to deformation, may yield a practical solution.

46. The required deformation of molding sand best suited for various foundry conditions has not been determined and the next step will be in this direction. The data as presented in this discussion on deformation will form a basic knowledge to determine the practical value of deformation control.

CONCLUSION

47. The results of this investigation on the deformation of molding sand show that it is possible to control the deformation. It is known how the most important physical properties affect the deformation. A summary of this information is of interest:

(1) Deformation increases rapidly as moisture increases.

(2) Deformation increases as the sand becomes finer.

(3) Deformation increases when the clay content is low or high.

(4) Deformation increases as the mold hardness increases.

(5) Deformation increases as sea coal addition increases. A maximum increase is reached with a moderate addition, after which deformation decreases slowly.

48. The practical value of deformation when considered alone is limited. However, when it is used to calculate the modulus of compression at yield load, it becomes a practical problem since it gives information as to the load carrying ability of the sand in conjunction with resistance to swelling of mold.

49. Modulus of compression may be increased by:

(1) Decreasing moisture content;
(2) Decreasing coarse material;
(3) Increasing clay content;
(4) Increasing mold hardness.

50. The strength of a molding sand as expressed by the compression test does not measure the complete strength property as does the sand resilience factor. Sand resilience factor makes proper deduction from the bond strength of a sand when the sand becomes what may be termed "short" or "brittle."

51. The sand resilience factor will undoubtedly prove a most useful method of expressing the strength of molding sand in the foundry. It adds to the compression test figures in both sensitiveness and more accurate evaluation of the practical bond strength of a sand.

52. The sand resilience of a molding sand may be increased by:

(1) Increasing Moisture Content;
(2) Increasing Fine Material;
(3) Increasing Clay Content;
(4) Increasing Mold Hardness;
(5) Increasing Sea Coal.

53. Improvement in measuring the strength of molding sands, made possible by sand resilience, will add materially to the value of sand control. The extension of sand control offers a most remunerative field in the foundry.

DISCUSSION

DR. H. RIES[1]: This paper has a mass of data that are interesting and need to be carefully studied. There is one question I want to ask. Let us refer to Fig. 8. Those curves, of course, represent the results of tests made with one clay, do they not? Now, if you took the same sand and another clay would you get practically parallel curves?

MR. DIETERT: They would indicate the same things as these set of curves do. They would not be quite parallel but they would have the same general trend and there would not be much crossing.

DR. J. T. MACKENZIE[2]: I would like to ask Mr. Dietert what he means by modulus of compression?

MR. DIETERT: Where the load is divided by the deformation.

DR. MACKENZIE: That is what we call modulus of elasticity in compression.

MR. DIETERT: Yes, that is right. We are taking a short cut here, as is explained in the paper. The resilience factor is not the same as it is in metals. We have put the term "sand" in front of the resilience to differentiate that from the resilience factor used in the strength testing of metals. In this case, we do not try to get the exact area underneath the stress-strain curve because it is divided by one-half in metals. In sand, we just multiply the compression load by the deformation times 1000 to get a convenient number. The number would be directly related in all cases to a true resilience factor. In other words, we get a resilience factor of 100, 200 or 300, depending upon the type of sand. Yet our factor, I believe, shows the same thing as the factors used by the metal men.

I would like to call attention to one point that may come up later in your study of this paper. It will be noted that sand resilience and compression tests do not agree in all cases. Any green strength test, whether shear, tensile or compression, is perfectly satisfactory for measuring whether or not you should add new sand or change the quantity of bonding material added, but I do not believe in all cases it measures necessarily the workable strength of the sand, because the sand could be brittle or short. The sand resilience factor would show this up. The compression strength may show the same as on a previous day's test, but the sand is different because it is dropping, particularly noticed by the men working in deep flasks. For that reason, sand resilience is of importance.

MEMBER: I wonder if Mr. Dietert is not opening the door to a new and valuable line of research? In olden days, the foundrymen and sand men tested their sand by feel. Part of that feel was translated into new tests. But the old sand man or the old foundryman today, after he has seen all kinds of sand tests, still wants to put his hand in the sand because it is telling him something which the usual tests do not. That something, I think, is what Mr. Dietert has in this new quality he calls resilience. I have noticed it many times. We get reports of a sand, we look at the reports, it tells us a lot, but yet there is something missing which we can only get through the hand feel. I think this new test is what has been missing in the past to give a better picture of the sand.

[1] Head of Geology Dept., Cornell University, Ithaca, N. Y.
[2] Chief Chemist, American Cast Iron Pipe Co., Birmingham, Ala.

Report of Technical Director, Foundry Sand Research Committee

Members American Foundrymen's Association:

One of the duties of the Chairman of the Sand Research Committee is to keep the membership informed of its activities through an annual report.

Some time ago we prepared a pamphlet on the methods for testing foundry sands*. This pamphlet has reached a third edition but, owing to the fact new tests have been developed and others have been improved, it has been found necessary to prepare a fourth edition, and the committee is now engaged, among other things, in getting this new edition ready. We hope to have it ready before long.

In addition to that, the committee is also preparing a pamphlet on the properties of sands, which will deal not only with the different properties of sand but it will also endeavor to indicate the causes of these properties and their effect on foundry work.

It is now 15 years since the Sand Research Committee began its work, and yet our unfinished work instead of getting less, seems to be growing larger, because our problems seem to be increasing in number. To accomplish as much as possible in the minimum amount of time, it was found desirable to appoint a number of sub-committees to wrestle with these different problems that confront us. We have ten of these sub-committees at the present time. I shall simply mention very briefly some of the results of their work, although a good deal of it may be summed up in one word—progress.

Grading

We have a sub-committee on Grading, which has been giving considerable attention to the formulation of what we call the "distribution factor." This committee reported on this at the Toronto Convention last year and the report has gone to press.

Bonding Clays

The Sub-committee on Bonding Clays is one that has a good deal of work to do. That committee has been giving considerable attention to formulating a satisfactory and, we hope, standard

* Testing and Grading Foundry Sands—Standard and Tentative Standards. First Edition 1924, Second Edition 1928, and Third Edition 1931.

NOTE: This report was presented at a session on Sand Research at the 1936 Convention of A.F.A. held in Detroit, Mich.

method for the testing of synthetic mixtures of sand and bond clays. It has made considerable progress, but its final report is not yet ready.

Strength Test

Another sub-committee has been studying the strength test. The method has been carefully studied in order to make the different tests comparable to a reasonable degree. One of the recommendations this committee is making, and which I think will interest all of you who are engaged in sand control, is that instead of using the old brass cylinder for ramming the sand, it is found more desirable to use a chrome plated steel cylinder. This does not wear out. The old brass cylinders showed a tendency to become slightly roughened on the inside and as a result did not give reliable results, the worn cylinder giving a lower strength. This new cylinder is now recommended.

An apparently minor item which has been found to be of some importance, is the method of filling the sand container. That will be dealt with in the report of the sub-committee which is to be issued shortly.

In making the tensile strength test, the committee had previously recommended that the load could be applied at the rate of one pound per minute, but this is now increased to 3 lb. per minute.

Another important item is the height of the sand core as rammed in the cylinder. At present, there is an allowed tolerance of one-sixteenth of an inch. The committee is recommending that this tolerance be reduced to one-thirty-second of an inch, and that for standard tests we should use a core which is exactly 2-in high. It may seem to some that it will take a lot of trouble to get the sand core down to those dimensions with such a small tolerance, but it is not as difficult as it would seem, moreover this change gives more consistent results.

SPECIAL PROBLEMS

There are some branches of the foundry industry which have special problems and, consequently, we have appointed sub-committees to deal with some of these. One of these is a sub-committee on steel sands and refractories, which was appointed to give special consideration to those molding sand problems arising within the steel division group. This committee has nothing to report as yet but among the things it is considering is a method for testing high dry strengths. There is another committee connected with that

same group, a sub-committee on "The Strength of Molding Sand at Elevated Temperatures," which has had to consider the resistance of molding sand to loading at different temperatures as well as the expansion and contraction behavior of molding sands under these same conditions. It will be understood, of course, in order to carry out this work a special type of high temperature furnace has to be designed. The committee has been studying several types already in use and is designing a type of its own, which is supposed to be an improvement on those already in use.

Hardness Testing

Then in connection with the hardness of mold, we have a sub-committee which has agreed on a simple method of calibrating the mold hardness tester, which is desirable at times. A hardness tester for testing the hardness of cores is also now being considered by the committee.

Durability

One of the sub-committees that has a large problem on its hands, as I have already mentioned this afternoon, is the Sub-Committee on Durability. It has made progress, but is not yet ready to report.

Fineness Test

Perhaps the Sub-Committee on Fineness Test finds that this test has, on the whole, been found to be very satisfactory. Certain changes in the test are however being recommended. One change is that the sodium hydroxide solution, used to disintegrate the sand, should be a 3 per cent instead of 1 per cent solution. The reason for change is that some sands do not disintegrate well with the weaker solution.

Buying Form

A point that may be of considerable interest is the appointment of a sub-committee for recommending a form to be used in ordering sands. It has been called a specification form but that is perhaps not exactly the right term to use. It is hoped the adoption of this form, which we hope to make public in the near future, will be of material assistance to both the producer and consumer.

Respectfully submitted,

H. RIES, *Technical Director, Foundry Sand Research Committee.*

Some Applications of Heat Treated Cast Irons in France*

By Marcel Ballay** and Raymond Chavy†, Paris, France

Abstract

Applications of heat treated gray irons are divided into four classes: (a) irons machinable as-cast, then hardened, (b) martensitic irons, either employed as-cast or given a draw, (c) martensitic irons, drawn then hardened by quenching and (d) austenitic irons, drawn then hardened. The authors then describe several French applications of commercial importance. Compositions and heat treatments are described and resulting physical properties are listed. The applications include automobile cylinder sleeves, gears, calibrating plates, support for grinding roller bearings, hydraulic pump pistons and air-cooled aviation cylinders.

1. The application of the hardening heat treatments, quenching and drawing to cast irons, is not a new idea in France. During the war years of 1914-1918, heat treatment was tried for cast iron shells containing a high percentage of steel scrap. Quenching and drawing was applied to an ordinary gray iron, but one which today probably would not be considered to be of the current ordinary types.

2. Actually, the results were not satisfactory.[1] Water or oil quenching of ordinary cast iron, having too high a critical quenching speed, led to internal defects (microscopic cracks), and to porosity. However, Jean Durand[2], in 1922, stressed the importance of the improvement in mechanical properties which could be attained by heat treatment. With an iron containing 3.20 per cent total carbon, 0.48 per cent combined carbon, 1.18 per cent silicon, 0.53 per cent manganese, 0.048 per cent sulphur

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† Foundry Metallurgist, Centre d'Information du Nickel, Paris.

[1] Portevin, A., *"Sur le traitement thermique des pièces moulées et spécialement des projectiles en fonte dite aciérée,"* Comptes Rendus, vol. 175, 1922, p. 27.

[2] Durand, J., *"Sur le traitement thermique de quelques fontes de moulage,"* Comptes Rendus, vol. 174, 1922, p. 748.

* Presented on behalf of the Association Technique de Fonderie de France, the French Foundry Technical Association, at a session on Cast Iron at the 1936 Convention of A.F.A. in Detroit, Mich.

and 0.208 per cent phosphorus, oil quenched at 1652° F. and drawn at 1200° F., the breaking strength was increased from 32,850 to 43,500 lb. per sq. in., and the total energy required to break the bars increased from 93 to 291 ft. lbs.

3. While the heat treatment of ordinary cast irons can, in certain cases, give interesting results, it is the alloy irons, having a low critical quenching speed, which have created the interest shown to-day in this subject. These irons allow lower quenching temperatures and particularly far less exacting cooling conditions. Risks of cracks have been reduced, and heat treatment can be applied to castings of complicated design.

4. In 1928, the influences of manganese, silicon and nickel were defined in a paper[3], and the principal methods of heat treatment applicable to cast irons classified. One of the writers cited this research work in a paper[4] before this Association in 1932.

5. Applications of heat treated gray irons can be divided into four groups:

(a) Irons, machinable as cast, hardened by a water, oil, or air quench, according to the composition, size and sections of the casting. A draw, even at low temperature, is always useful, reducing considerably the brittleness caused by quenching.

(b) Irons martensitic as cast, employed upon occasion as such, but more often after drawing. A draw between 930 and 1200° F. results in a hardness of 300 to 340 BHN, which still permits machining without excessive difficulty with this type of iron.

(c) Irons of the preceding group can be rendered machinable by drawing at 1112 to 1200° F., then hardened by a treatment consisting of an air quench, or even relatively slow cooling in the furnace. This method is adopted for heavy castings, or those whose complicated design causes risks of deformation or cracks from quenching.

(d) Austenitic irons hardened after machining by a draw, transforming the austenite to martensite, have been proposed. One application has been cited[5] by Delbart and

[3] Guillet, L., Galibourg, J., Ballay, M., *"Sur les points critiques et la trempe martensitique des fontes au nickel et au nickel-chrome,"* COMPTES RENDUS, vol. 187, 1928, p. 14.

[4] Ballay, M., *"Contribution to Study of Martensitc Quenching of Alloy Cast Irons,"* TRANS. AM. FOUNDRYMAN'S ASSOC., (1932) vol. 40, pp. 15.

[5] Delbart and Lecoeuvre, *"Etude de quelques propriétés physiques d'une fonte qusténitique au nickel-manganèse a basse teneur en carbone,"* BULL. ASSOC. TECH. DE FONDERIE, July 1934, pp. 279-288.

Lecoeuvre. To this group could be added precipitation hardening, which however has not been applied to date.

6. We will endeavour in this paper, of limited length, to describe a few French applications of heat treated gray irons of the first two groups, (a) and (b), limiting ourselves to those more important applications as have received practical industrial endorsement during the past several years. There are numerous other experiments under way which we cannot enumerate at the present time, through lack of space, concerning the solution of various diversified problems including: diesel or internal combustion motor cylinder blocks, motor-cycle cylinders, motor cams, piston rings, cylinder rolls for small sectioned shapes, pump bodies handling abrasive liquids, pump pistons, forging and stamping dies, lathe mandrels, etc.

REPLACEMENT AUTOMOBILE CYLINDER SLEEVES

7. We will not elaborate on the subject of automobile cylinder sleeves, which has been recently treated in detail in an interesting paper[6], except to mention that in France similar results have been obtained, and that heat treated sleeves have been rather extensively employed for the past 5 years.

8. Numerous compositions have been tried for such castings. Among the most interesting and economical, due to excellent wear resistance, are the martensitic irons, treated after machining. The usual average composition is:

	Percent
Total carbon	2.8 to 3.0
Silicon	1.5 to 1.8
Manganese	0.8 to 1.0
Phosphorus	0.30
Nickel	2.5 to 2.8
Chromium	0.5 to 0.7

9. These irons are usually produced in the cupola. The nickel and chromium additions are made in part to the charge in the form of risers, etc., and in part to the ladle in the form of nickel-silicon shot. An iron of the above composition is machinable as cast, the Brinell hardness being around 270 to 300. The sleeves are generally cast with a collar at each end, to avoid any deforma-

[6] Eddy, W. P., *"Heat Treated Gray Iron Cylinder Liners,"* TRANSACTIONS, A.F.A., vol. 42 (1934) pp. 129-147.

tion which might be produced during machining or oil quenching. After machining, save for finishing, the castings are quenched in oil at 1526 to 1562° F., then drawn at 482 to 572° F. so as to relieve internal strains and brittleness. Allowance must be made in machining for a very slight increase in diameter (about 0.004 in. for a sleeve of 4-in. diameter). After complete treatment, the hardness is around 450 Brinell and the metal is practically unmachinable. Both interior and exterior finishing is accomplished by grinding, one of the collars being cut off at this time, and the other remaining as a reinforcement for pressing the liner into the cylinder.

10. The use of such heat treated sleeves in France for reboring both touring and commercial cars, is extensive, while certain manufacturers have even started employing heat treated sleeves in new motors, taking certain special precautions as to cooling conditions for the cylinder top, this being more necessary in sleeved than in ordinary motors (Fig. 1).

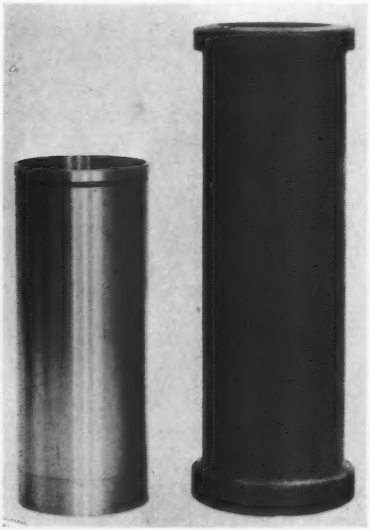


FIG. 1—AUTOMOBILE REPLACEMENT SLEEVES IN MARTENSITIC NICKEL-CHROMIUM IRON, HEAT TREATED AFTER MACHINING: (RIGHT) SLEEVE AS-CAST, (LEFT) FINISHED SLEEVE (ETABS. P. BUCHLY, PARIS; FONDERIES MONERNES DE L'AUTOMOBILE, BONDY.)

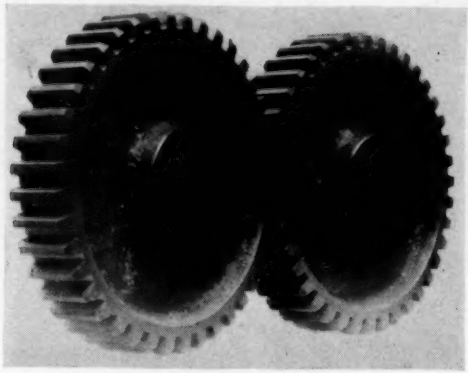


FIG. 2—VENTILATOR GEARS CAST IN MARTENSITIC NICKEL-CHROMIUM IRON. (ETABS. O. G. PIERSON, PARIS; FONDERIES LOBSTEIN, ARGENTEUIL.)

VENTILATOR GEARS

11. In certain instances ventilator gears (Fig. 2) operate under very bad lubricating conditions, and even in the presence of fine abrasive matter, which accelerates wear of the teeth. Ordinary pearlitic irons of 180 and 220 BHN have been found to be far from satisfactory, due to very rapid wear in service, while alloy steels entail a considerable increase in machining costs.

12. Comparative tests on a test bench between a pearlitic iron, a self-hardening nickel-chromium steel and an air-quenched nickel iron, definitely indicated the superiority of the treated nickel iron as concerns wear as well as cost (in comparison to the alloy steel). The approximate composition of this iron was:

	Per Cent
Total Carbon	2.8 to 3.0
Silicon	1.5 to 1.8
Manganese	0.8 to 1.0
Phosphorus	0.30
Nickel	2.5 to 2.8
Chromium	0.5 to 0.7

13. The metal, melted in a crucible, had a hardness of around 270 to 300 BHN as cast. For certain gears working under normal conditions with suitable lubrication, the castings are sometimes employed without treatment, while in other cases they are machined completely and then air quenched at 1526°F. and drawn at 572°F. During the quench, the gear is mounted on a horizontal shaft turning slowly so as to effect a uniform quench

of all teeth. Brinell hardness of the teeth can be from 360 to 420 without undue brittleness.

BALL BEARING CALIBRATING PLATES

14. Castings such as ball bearing calibrating plates (Fig. 3) mounted in special machines, are subjected to excessive wear by the balls rolling under rather heavy pressure in the presence of powdered emery. Since the plates weigh from 330 to 550 lb. each, their dissembling and machining is a costly item, and since the average service for such plates between rectifications was only around 2 days, a large number of machines were required to maintain normal production. Within the past few years, following trials with various materials, a nickel-chromium iron, martensitic as cast and drawn to a Brinell hardness of around 340, has been employed, the composition being:

	Per Cent
Total Carbon	approx. 3.2
Silicon	1.5
Manganese	1.0
Phosphorus	0.4
Nickel	4.0
Chromium	0.8

15. Due to the weight of metal involved, this iron is produced in the cupola with a charge composed of risers and scrap from preceding melts, used plates, and a mixture of 2.5 per cent chromium pig, hematite ordinary iron and silicon steel scrap (to lower the carbon content). To insure a martensitic state as cast,

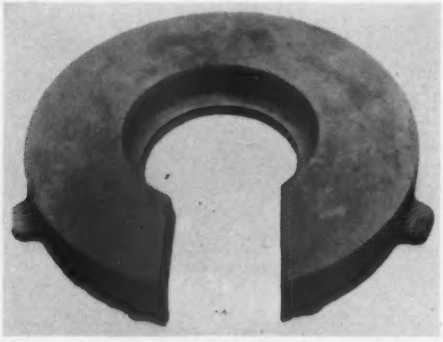


FIG. 3—BEARING BALL CALIBRATING PLATE CAST IN NICKEL-CHROMIUM IRON, MARTENSITIC AS-CAST. (CIE. D'APPLICATIONS MECANIQUES, IVRY — FONDERIES GAUTHIER & VAUDOUX, IVRY).

these large pieces are removed from the mold at a red heat about 45 minutes after pouring, that is, at a temperature around 1500 to 1650°F. They are then placed in a well aired section of the foundry floor to obtain as rapid cooling as possible. The hardness specified for each plate before drawing is over 360 BHN, though usually, due to removal from the mold at a red heat, hardnesses of around 420 are obtained.

16. Drawing is a simple process, since there is no deformation to be feared. They are placed directly in a furnace heated to about 1020°F., held at this temperature for 2 or 3 hours and then are allowed to cool in the furnace, so as to avoid the possi-

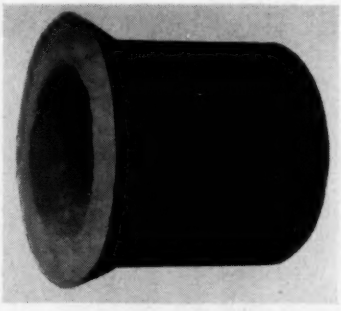


FIG. 4—CYLINDER SUPPORT FOR GRINDING ROLLER BEARINGS MADE IN AN IRON MARTENSITIC AS-CAST. (CIE. D'APPLICATIONS MECANIQUES; FONDERIE GAUTHIER & VAUDOUX).

bility of any internal strains from rapid cooling, in view of the numerous refinishing operations required during service. The service life of these heat-treated nickel-iron plates has been found to average 10 times longer than the ordinary iron plates of 180 to 200 BHN previously employed, whereas the alloy iron, including the treatment, only costs 2 or 3 times more.

CYLINDRICAL SUPPORTS FOR GRINDING BEARING ROLLERS

17. The problem in connection with cylindrical support for grinding bearing rollers is similar to that of the calibration plates, except that cost of the finished parts is considerably higher due to the large amount of machining involved and the necessity of working within narrow tolerances.

18. Treated chromium steels are sometimes employed for these parts, but usually a nickel-chromium iron of the same com-

position and treatment as that used for the calibration plates previously cited, is preferred. However, these parts, being much lighter in weight (65 to 110 lb.) and in section, are allowed to cool in the mold, which suffices to obtain a martensitic quench and a BHN of 360. Being used in the same plant, drawing is done at the same time as the calibration plates (Fig. 4).

HIGH PRESSURE HYDRAULIC PUMP PISTONS

19. High pressure hydraulic pumps operate at high water heads and under very heavy pressures of around 11,000 lb. per sq. in. The piston plnnger of a "double piston" type, (Fig. 5), is worn very rapidly by the packing, wear being accelerated by the presence of sand and rust particles in the water.

20. Tests with case-hardened and even nitrided steels did

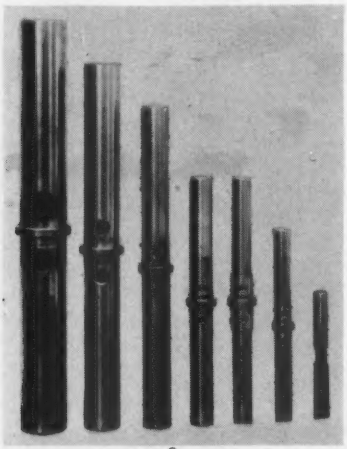


FIG. 5—MARTENSITIC NICKEL-CHROMIUM IRON PUMP PISTONS. (ETABS. P. MENGIN, MONTARGIS; SOC. NOUVELLE DE LA CHALEASSIERE, SAINT-ETIENNEQ.

not give good results. While a self-hardening, nickel-chromium steel stood up well, a gray nickel-chromium iron of martensitic structure was tried out with extremely interesting results. The composition was approximately:

	Per Cent
Total Carbon	3.0
Silicon	1.5
Manganese	1.0
Phosphorus	0.4
Nickel	4.2
Chromium	0.8

21. This iron is melted in the cupola with the nickel-chromium additions included in the charge. The larger pistons which weigh over 225 lb. are removed from the molds at a red heat, while those of smaller dimensions are allowed to cool normally in the mold.

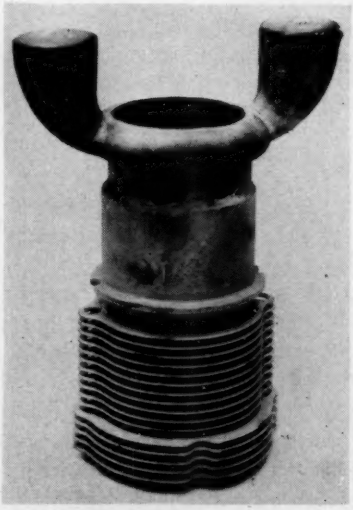
22. The as-cast hardness is around 360 to 420 BHN, and the pieces are employed after drawing at a very low temperature, 390 to 480°F., in a drying oven. Machining is effected with tungsten carbide tools, with a final polishing operation on a precision grinding machine.

AIR COOLED AVIATION MOTOR CYLINDERS

23. Air cooled aviation motor cylinders present a rather difficult problem, since the iron must possess several distinctive and different characteristics which are:

(a) High mechanical properties permitting thin sections, and consequently lightness.

(b) Facility in readily casting the thin fins of 1.5 to 2



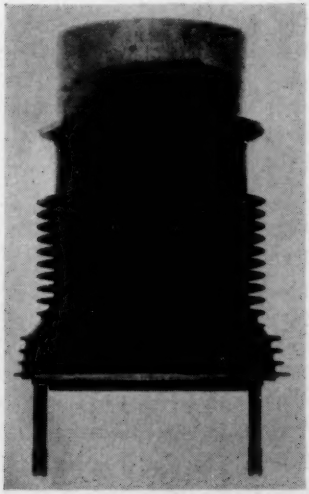


FIG. 6—(LEFT) MARTENSITIC NICKEL IRON AVIATION MOTOR CYLINDER, PHOTOGRAPHED AS-CAST WITH SPRUE AND RISER. (SOC. DES AVIONS PORTEZ, PARIS).
FIG. 7—(RIGHT) SAME CYLINDER AS SHOWN IN FIG. 6 ENTIRELY MACHINED.

mm. (0.059 to 0.078 in.) thickness, which are in turn but 7 mm. (0.276 in.) apart.

(c) Excellent resistance to wear.

(d) Excellent stability (no internal strains), to avoid deformation in service upon repeated heating and cooling.

24. To meet all these requirements, a low carbon iron has been employed, though as far as wear resistance is concerned, an iron of higher carbon might have been preferable.

25. To obtain a high hardness, a martensitic iron, drawn before machining to a Brinell hardness of around 300, has since been used. This iron has the following approximate composition:

	Per Cent
Total Carbon	2.8
Silicon	2.0
Manganese	1.0
Phosphorus	0.6
Nickel	4.2

It is melted in the crucible with a mixed charge of hematite pig and 1.5 per cent phosphorus "PL-3" pig.

26. Pouring is done at as high a temperature as possible, around 2550°F., into molds, the essential parts of which are of an extra-siliceous sand bound by linseed oil. Fig. 6 illustrates a piece as cast with its sprue and riser, and Fig. 7, a piece after machining. The Brinell hardness as-cast varies from 360 to 420, and the iron can be machined and used in this state, but preferably is drawn at a temperature of 930 to 1070°F. to reduce machining time and suppress internal stresses.

27. The cylinders are placed in the furnace cold, and heated very slowly for 2 or 3 hours up to the drawing temperature, at which temperature they are kept for about a half an hour, following which they are withdrawn from the furnace and immediately placed in soaking pits to cool very slowly. Such slow heating and cooling during the drawing operation is required due to the inevitable presence of cementite, producing cracks if more rapid operations are employed.

28. Despite a 0.5 to 0.7 per cent phosphorus content in this iron, its mechanical properties after treatment are considerably above those specified in France for cast irons termed "extra- résistantes." Brinell hardness is regulated between 280 and 320 and the transverse strength on a Frémont test specimen varies between

1430 and 1670 lb.. as compared to a specification of but 1200 lb. for the so-called "extra-résistantes" irons.

29. Despite a rather low carbon content, the iron also exhibits excellent wear and resistance in service. After 700 hours of service, the cylinder diameters were found to be but a few hundredths of a millimeter (1 mm. equals 0.03937 in.) out of true in the zone of maximum wear.

CEMENT PUMP BODIES

30. Cement pump bodies previously were made of ordinary gray cast iron or cast steel and wore very rapidly, due to the abrasive action of the sand grains contained in the concrete moving through these parts.

31. Successful tests were made with a martensitic iron containing about 4.2 to 4.5 per cent nickel, 0.6 to 0.8 per cent chromium and 1 per cent manganese, which is hard and unmachinable in the as-cast condition. Before machining, the pieces were drawn at a temperature of between 600 to 620° C. (1112 and 1148° F.) to obtain a maximum softness. The pieces were then completely machined and quenched in calm air at 850° C. (1562° F.), this being followed by a drawing at 200-250° C. (392-482° F.) After this treatment, the Brinell hardness was between 400 and 450. Improvement in wear resistance has been considerable, and the increased service life of these parts has been such that a very important economy has been recorded.

ROLLERS FOR WEAVING LOOMS

32. Rollers for weaving looms are entirely machined and wear rapidly due to the contact of the outer part upon the roller race. Up to the present, they were cast in ordinary gray pearlitic cast iron of 200 to 230 Brinell. A test was made on about 100 pieces with a gray nickel-chromium cast iron of martensitic quench, of the following composition:

Element	Per Cent
Carbon	3.0-3.3
Silicon	1.5-1.8
Manganese	0.8-1.0
Phosphorus	0.3
Nickel	2.5-2.8
Chromium	0.6-0.8

33. The hardness of this iron in the cast state was about

270-300 Brinell and machining could be done in the ordinary way. After machining, the pieces were quenched in calm air at 850° C. (1562° F.), then drawn at about 250° C. (482° F.) to obtain a Brinell hardness of 400; and finally ground on the outer surface and the hole. Results obtained in service have been excellent. The life of the pieces has been increased more than five times the average service life. This solution has been generalised in the spinning mills which have made the experiments.

FIG. 8—MICROPHOTOGRAPH OF A HIGH-CARBON MARTENSITIC NICKEL-CHROMIUM IRON (MAGNIFICATION 100X).

CONCLUSION

34. When first proposed, the heat treatment of cast irons was considered to be an operation replete with difficulties and troubles. Actually it is becoming an increasingly general and readily controlled solution to the problem of obtaining hard or very hard machinable gray irons, for which purpose alloyed irons offer particular advantages. Numerous articles on this subject have been written during the past 7 years, citing a wide range of applications, which have proved that the idea is gaining headway, and that heat treatment can be applied equally as well to cast irons as to steels. In this paper, we have sought to describe only certain definitely proved French applications.

35. All of the possibilities of this method of hardening ma-

chinable irons have not yet been utilized. We would like in closing to draw attention to two important points:

(1) Quenching is most often utilized for increasing the hardness, the improvement in other mechanical properties being considered as secondary. It is true, of course, that a high-quality iron with or without alloy additions will produce higher strength, transverse and shearing values than a mediocre iron, when treated. However, mechanical properties of the best irons can be still further improved by a judicious heat treatment, thereby elevating very considerably the "ceiling" of mechanical properties obtainable.

(2) With unalloyed irons, when it is desired to increase the hardness and mechanical properties, it is necessary to lower the carbon, that is to say, the proportion of graphite. When only compression, transverse, tensile and shearing strengths are of import for the pieces to be cast, there is no disadvantage, but if good friction and wear resistance is required, a certain quantity of graphite is necessary. For numerous applications involving wear, the best irons are those which are hard and contain a considerable amount of graphite. These two conditions are contradictory in the case of ordinary irons, but can be readily realized with alloy irons subjected to heat treatment.

36. We will cite only one example, referring to an iron containing:

	Per Cent
Total Carbon	4.08
Combined Carbon	0.60
Graphitic Carbon	3.48
Silicon	1.52
Manganese	0.88
Nickel	4.69
Chromium	1.05

cast in test bars of 40 mm. (1.57 in.) diameter. With no alloys present, a gray iron of the same graphitic carbon content would have a Brinell hardness of about 160, while the iron alloyed with nickel-chromium has an average hardness of 270 as cast. Its appearance is illustrated by the microphotograph in Fig. 8.

DISCUSSION

This paper is the official Annual Exchange Paper of the Association Technique de Fonderie de France, the French Foundry Technical Association. In absence of the authors, the paper was presented by R. F. Harrington, metallurgist, Hunt-Spiller Mfg. Co., Boston.

H. C. GRIGGS[1] (*Submitted as Written Discussion*): In Messrs. Ballay and Chavy's excellent paper on "Applications of Heat Treated Cast Irons," mention is made in the introduction of four classes of heat treated gray irons. These are divided into headings (a), (b), (c), and (d). This discussion is limited to those irons falling into class (a), namely, "irons machinable as cast, then hardened."

In paragraph 12, the analysis of ventilator gears is given as follows:

	Per Cent
Total Carbon	2.8 —3.0
Silicon	1.5 —1.8
Manganese	0.8 —1.0
Phosphorus	0.30
Nickel	2.5 —2.8
Chromium	0.5 —0.7

Paragraph 13 gives the method of casting, hardening and tempering.

We regularly cast a cupola iron used for gears and cams with the following analysis:

	Per Cent
Total Carbon	2.6 —2.9
Silicon	1.8 —2.0
Manganese	1.0 —1.2
Phosphorus	0.2 —0.3
Nickel	0.75—1.25
Molybdenum	0.60—0.90
Chromium	0.40

This metal as-cast is a completely fine grained pearlitic gray iron with small nucleii of primary graphite and has a BHN of 200-225 as-cast. We then employ the following heat treatment to make the iron martensitic:

Heat to 1550-1575° F., quench in oil.

Draw at 400-425° F. depending on section and hardness desired.

This gray cast iron, when properly heated and quenched, will develop a BHN of 475-500 on sections up to 3-in. thick. Drawn at the temperature given above, it will have no resultant drop in hardness nor any undue brittleness. This is as compared with 360 to 420 in the case of the iron mentioned by the authors.

In cupola metal, this nickel-molybdenum mixture is much easier to cast than the nickel chromium mixture mentioned by the authors. Let us take, for example, a casting weighing 200 lb. The average ferro-

[1] Metallurgist, The Waterbury Farrel Foundry & Machine Co., Waterbury, Conn.

chromium in this country contains 70 per cent chromium. "F" nickel shot, most commonly used for nickel spout alloy additions, contains 92 per cent nickel. Ferro-molybdenum runs around 60 per cent contained molybdenum. For this discussion let us use the lower alloy limits in each case.

In the case of the authors' cast iron, 2.50 per cent nickel and 0.50 per cent chromium will be added. This means an addition of 5-plus lb. of nickel and 1.45 lb. of ferrochromium of the above compositions to give the required percentages.

In the case of our metal, 0.75 per cent nickel and 0.60 per cent molybdenum are specified. The chromium we obtain from a chromium-nickel bearing silvery pig iron, also a small amount of nickel, which for the purposes of this paper we will omit, although naturally it is of value in saving the cost of nickel additions. By the same method of figuring as the above, we must add 1.5-plus lb. of nickel shot and 2.00 lb. of ferromolybdenum. In small castings, the smaller the amount of alloy additions, (which are solid when added on the spout) the hotter the iron in the ladle. This is a decided advantage in casting low-carbon, alloyed cupola irons, because even unalloyed these irons "set" very quickly in the ladle.

With ferrochromium at 12 cents per lb. of contained chromium, "F" nickel shot at 32 cents per lb. of contained nickel, and ferromolybdenum at 95 cents per lb. of contained molybdenum, the saving in cost of our mixture for alloy, over the authors' metal, in a casting weighing 200 lb. is about 3 cents per casting.

The writer considers this paper to be of great merit, but has observed that most foreign contributors seem to be totally unfamiliar with the use of molybdenum insofar as their published works are concerned. The uses of nickel-chromium-molybdenum irons instead of nickel-chromium of the (a) classifications of the paper warrant their consideration by those interested in hardened gray irons.

J. W. BOLTON[2]: In paragraph 5, section (d), the authors make the statement—"Austenitic irons hardened after machining by a draw, transforming the austenite to martensite, have been proposed." And then, later in the same paragraph—"To this group could be added precipitation hardening, which however has not been applied to date."

That paragraph is very suggestive to people working in heat treated cast irons. I assume, of course, when the authors used the term "austenitic cast irons," they referred to irons of non-stable composition because with fully stable irons, there is very little you can do to the matrix by drawing or quenching.

When the authors refer to "precipitation hardening," are they referring to precipitation of martensite or do they refer to the addition of some special material? For example, in the case of steel and copper, copper can be used for that effect, to produce the precipitation hardening effect outside the normal iron-carbon effects.

I may add to this discussion of heat treatment that there is one type that has not been mentioned. In the very high chromium corrosion re-

[2] Metallurgist, Lunkenheimer Co., Cincinnati, O.

sistant cast irons, a high temperature quench often will increase the corrosion resistance without changing much one way or the other the hardness or strength of the irons which we get from stainless steels.

MEMBER: I would like to have information as to how that high carbon, the 4.08 per cent cited in the example of paragraph 36, is obtained?

MEMBER: A question which may be somewhat outside the range of the paper is, what is the ageing effect due to heat treatment? Another way to phrase the question is, what effect does the tempering of cast iron have on aging qualities of the iron in regard to the change of structure?

MR. BALLAY (*Submitted as Written Closure*): We are submitting answers to the three questions raised during the discussion of our paper. The first two questions are easy to answer but this is not so with the third, which is not at all clear to us. We shall, however, endeavor to reply to the best of our ability.

(1) In replying to Mr. Bolton, we believe that the hardening of austenite by drawing can be done in two ways:

(a) By the transformation of austenite into martensite either during the draw or during the cooling that follows. This effect is well-known on nickel and nickel-chromium steels. Cast irons of suitable composition may have a more or less stable austenitic structure after cooling in the molds. When re-heated, to 930° F. (500° C.) for instance, the austenite will decompose into martensite, and according to the stability of the initial austenite, a greater or less hardness will result after cooling. To obtain a substantial hardening, it is important to start with a cast iron containing just the necessary amount of alloying elements to make it austenitic as cast. In the presence of an excess of nickel or chromium after cooling in the mold, the cast iron will be more stable, with little or no hardening by tempering, a substantial increase in hardness being possibly obtained only by a very long heating.

(b) Through precipitation of a compound, *i. e.* the well-known precipitation hardening. This type of cast iron hardening is much less known, and to our knowledge, no paper has been published on this subject to date. One of the authors, however, has obtained quite definite increases of hardness in some cases, such as in cast iron containing nickel and beryllium, or possibly nickel and aluminum.

In fact, both the martensitic or precipitation hardening referred to above are more or less mingled. Some people are not far from believing that martensite formation, *i. e.* the hardening of steel, is in relation to the precipitation of carbides. On the other hand, in the case of precipitation hardening, the precipitation of the compound brings about a modification of the austenite, which in turn acts on the stability of this constituent and its ability to give martensite. The two phenomena can, however, be separated in cases where hardening takes place without causing magnetism as is so for some austenitic cast irons containing beryllium. The theory of the formation of martensite cannot then be maintained, as this constituent is magnetic.

It is quite possible that the hardening of the austenitic cast irons containing nickel, maganese and chromium, which Delbart has studied,

is not entirely due to martensite formation but, in part, to the precipitation of a compound, the nature of which is unknown.

(2) In answer to the question on high carbon, the 4.08 per cent carbon value mentioned in the paper is quite correct, and not at all exceptional for cast iron applications, such as chilled rolls.

The nickel-chromium cast iron of high carbon content referred to in our paper was obtained by melting a high carbon white Swedish pig iron in a crucible containing some coke. In France, many blast furnaces supply a non-phosphorus white pig iron of low silicon content, which can be remelted in the cupola, in crucibles or in electric furnaces.

We do not claim that high carbon gray alloyed cast irons referred to in our paper, are industrially used, but we wished to call attention to the possibility of obtaining a hard gray cast iron of high graphite content giving good wear and friction resistance.

(3) Unfortunately, we do not quite understand what the member had in mind when requesting information on the ageing effect due to heat treatment, with regard to changes in structure. It is evident that the drawing which transforms austenite into martensite also brings about changes in structure. Precipitation hardening, on the contrary, may change the hardness without any structural modification being visible under the microscope. As regards the influence of drawing, say at 930° F. (500° C.), on the stability, the effect is certainly favorable, particularly on cast iron martensitic as cast, for removing strains and generally improving the mechanical properties. This is quite clearly shown by the deflection tests, which give higher values on drawn test pieces as compared with martensitic, though the hardness values are lowered by the treatment.

Effect of Tuyere Height on Carbon Pick-up in the Cupola

By H. V. Johnson* and J. T. MacKenzie,** Birmingham, Ala.

Abstract

As little work has been published on carbon pick-up of iron as affected by the height of the tuyere above the sand bottom in cupola melting, the authors undertook an investigation to secure data on this problem. Using pitch coke, petroleum coke, and standard foundry coke as fuels in a small portable cupola, two series of heats were run, with varying tuyere heights. The first series was composed of charges of low carbon steel bolts and rods and 15 per cent silicon pig and ferromanganese. The second series was composed of charges of high carbon, high-silicon steel and 3 per cent silicon pig iron. Chemical analyses were run on chill samples and test bars. Some conclusions drawn were that increasing heights of tuyeres increased carbon pick-up very little, intermittent flow showed a higher carbon over continuous flow, carbon pick-up increases with a rise in temperature of the iron and the contact of the melted steel with the incandescent coke is doubtless affected by the degree of tenacity with which the slag clings to the pieces of coke after each tap. A detailed description of the operation of the small cupola is given as an appendix to the main body of the paper.

1. Little work has been published on the carbon "pick-up" of iron as affected by the height of the tuyeres above the sand bottom in cupola melting. The general opinion of most metallurgists seems to be expressed by Piwowarsky who says: "Carburization first occurs in the fluid condition when the steel is in intimate contact with the incandescent pieces of coke. This is so much the greater the higher the melting zone lies above the tuyeres and the deeper the coke bed is under the tuyeres, or, in other words, the longer the time of contact." Further, it

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Note: This paper was presented at a session on Cast Iron at the 1936 Convention of A.F.A. in Detroit, Mich.

is generally believed increased temperatures result in higher carbon pick-up.

TESTS TO DETERMINE EFFECTS ON CARBON PICK-UP

2. A series of tests were conducted by the authors to determine just what effect on carbon pick-up would be obtained under different conditions.

Cokes Used

3. Three cokes were selected to be used, namely; a standard foundry coke of the Birmingham district, a pitch coke, and a petroleum coke. Sufficient quantities for the tests were selected and well mixed, then stored under sheds until needed. As the pitch and petroleum cokes were approximately the same size, 3 in. to 5 in. lumps, the foundry coke was broken up to about this size.

The Cupola

4. The cupola used was a portable type (see appendix), with blower, motor and stack all mounted on wheels. The shell was 31 in. in diameter, lined to 21 in. with clay brick, and maintained cylindrical by daubing before each heat. The lining was straight from mantle to top.

5. Air was introduced through two tuyeres, 4½ in. in diameter, and blast was supplied by a small fan type blower. The tuyeres were 4 in. above the bottom sand in the first group of heats in the first series of tests, were raised to 16 in. above the bottom sand in the last group, and, subsequently, lowered to their original position during the last group of heats in the second series of tests. There was a difference in bed volume of around 300 per cent between the high and low positions of the tuyeres.

6. The furnace had an overall height of 6 ft., and to maintain the same distance above the tuyeres, when the bed was raised, the top was built up 12 in. higher with clay brick. As there seemed to be no effect due to this height, during the last series of heats, it was discontinued in favor of using an extension, brick lined, that was some 24 in. in height.

Charges for First Series

7. Charges for the first series of heats were composed of 125 lb. of low carbon steel bolts and rods of from ½ in. to 1¾ in.

in diameter, cut to lengths of approximately 8 in. A large quantity of this scrap was well mixed and stored for the tests. A 500 lb. Fairbanks scale was used to weigh charges of steel.

8. Each charge of steel was raised in silicon content by the addition of 20 lb. of pig iron containing 15 per cent silicon, and in manganese by adding 5 lb. of 80 per cent ferro-manganese. These alloys were charged wrapped in paper bags on the metal in the center of the cupola. A grocery scale, accurate to ½ lb. was used for weighing alloys. Eight charges of 150 lb. each were charged during each heat.

Charges for Second Series

9. Charges for the second series of heats were made up of 66½ lb. of high-carbon high-silicon steel, and 33.5 lb. of 3.00 per cent silicon pig iron. The steel was specially prepared for these tests, melted in an electric furnace and cast in twin-pigs weighing 15 lb. each. The electric furnace made three taps, each of which varied slightly in silicon and carbon content, so proportionate weights of each tap were used to make up 66.5 lb. of metal. These proportions were: Tap 1 (Si, 1.77 per cent; C, 0.74 per cent) 14.5 lb.; tap 2 (Si, 1.74 per cent; C, 0.82 per cent) 34 lb.; tap 3 (Si, 2.04 per cent; C, 1.28 per cent) 18 lb. This method eliminated those variations that arise in small cupola operation due to use of high content alloys, and control showed an expected improvement throughout the entire second series.

Method of Charging

10. The cupola held four charges when first filled, and when melting began two more charges were added. The last two charges were used to keep the cupola filled to the top, and when these had been charged coke was used. Previous experience had shown that the blast pressure fell off rapidly unless the cupola was kept fully charged during the entire heat.

11. The bed was burned to a bright cherry red by natural draft to a height of 40 in. Then 10 in. of green coke were added to make a bed of 50 in. above the tops of the tuyeres. Bed coke was fairly constant in size, from 3 in. to 5 in. lumps, but that used between charges was slightly smaller, 2 in. to 3 in. lumps. The weight of the coke between charges was 13⅓ per cent of the weight of the steel, or, in the first series, 20 lb., and in the second 13⅓ lb.

Pouring Specimens

12. The first metal from the cupola was tapped into a 200 lb. ladle that had been previously heated. The metal of the first two ladles was discarded, and specimens were poured from all the other ladles. These specimens were 1½ in. x 1½ in. x 6 in. chill specimens. In addition, the fifth ladle was used to pour a mold containing four 2 in. x 1 in. x 24 in. test bars. All the iron was weighed at the completion of the heat. One heat which showed an abnormal loss was rejected.

13. In the second series of tests, practice was similar to that in the first, except that all ladles were used to pour chill specimens. The fifth ladle was used to pour test bars, and in some heats the third ladle was used to pour test bars to give a check against those in the fifth ladle.

14. Each ladle of iron weighed approximately the same as the charge for that heat, namely, 150 lb. in the first series, and 100 lb. in the second. Temperatures were read with a Leeds and Northrup disappearing filament optical pyrometer.

Chemical Analyses

15. The chemical analyses listed for the heats were run on chill samples in all cases except where test bars were poured. These analyses were made by the standard A.S.T.M. methods. In plotting the results, an average of the analyses of all ladles was used. Sulphur, both evolution and gravimetric, manganese, and phosphorus were run only on the test bars. Those ladles from which only chill specimens were poured were analyzed only for silicon and carbon.

Plotting Results

16. Fig. 2 shows the carbons plotted by corrected values, using as a base, for the first series irons, Si., 2.00 per cent; Mn., 1.25 per cent; P., 0.16 per cent and for the second series irons, a base of Si., 2.00 per cent; Mn., 0.48 per cent; P., 0.25 per cent. These corrections were made by the formulas.

Corrected Carbon = C + 0.3 (Si.—2.00 + P.—0.16) —0.04 (Mn.—1.25) in the first series, and

Corrected Carbon = C + 0.3 (Si.—2.00 + P.—0.25) —0.04 (Mn.—0.48) in the second series.

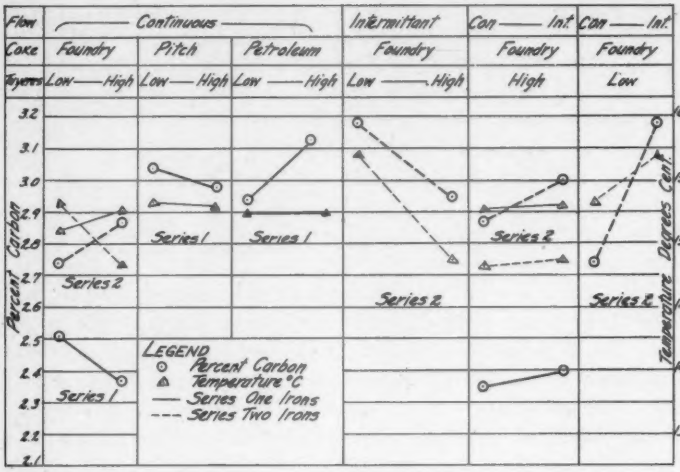

FIG. 1—CARBON PICK-UP AS AFFECTED BY HEIGHT OF TUYERE AND BY INTERMITTENT AND CONTINUOUS FLOW.

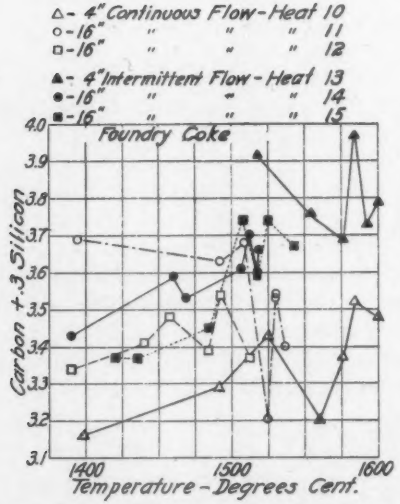
△- 4" Continuous Flow - Heat 10
○-16" " " " 11
□-16" " " " 12
▲- 4" Intermittent Flow - Heat 13
●-16" " " " 14
■-16" " " " 15
Foundry Coke
Carbon + .3 Silicon
Temperature - Degrees Cent.

FIG. 2—RELATION OF TEMPERATURE AND CARBON—.3 SILICON.

Table 1

DATA OF EACH HEAT SHOWING AVERAGE COMPOSITION OF IRONS.

Heat No.	Kind Coke	Height Tuyeres, Inches	Melt'g Loss, Per Cent	Blast Press. Ounces	Composition of Iron, Per Cent — C	Si	S	Mn	P
Series One—Continuous Flow									
1.	Fdry.	4	3.6	5.2	2.51	2.01	0.091	1.15	0.16
2.	Ptrl.	4	2.9	5.8	2.88	2.34	0.141	1.47	0.16
3.	Ptch.	4	1.8	4.9	3.12	1.61	0.069	1.17	0.17
4.	Fdry.	16	4.7	4.9	2.52	2.01	0.091	1.82	0.18
5.	Ptrl.	16	2.6	5.2	3.17	1.71	0.130	1.20	0.15
6.	Ptch.	16	1.5	4.6	3.01	1.81	0.063	1.38	0.18
7.	Fdry.	16	2.3	5.2	2.22	1.89	0.081	1.06	0.24
Series One—Intermittent Flow									
8.	Fdry.	16	2.5	5.2	2.50	2.26	0.100	1.54	0.21
9.	Fdry.	16	3.6	5.4	2.24	2.41	0.092	1.61	0.20
Series Two—Continuous Flow									
10.	Fdry.	4	4.6	4.9	2.71	2.10	0.054	0.48	0.28
11.	Fdry.	16	3.9	5.0	2.88	2.15	0.066	0.45	0.20
12.	Fdry.	16	4.2	4.9	2.80	2.03	0.071	0.50	0.23
Series Two—Intermittent Flow									
13.	Fdry.	4	3.9	5.2	3.11	2.28	0.064	0.46	0.31
14.	Fdry.	16	4.6	4.9	2.86	2.18	0.062	0.48	0.21
15.	Fdry.	16	4.3	4.8	2.93	2.10	0.061	0.44	0.27

DISCUSSION OF RESULTS AND CONCLUSIONS

17. A careful examination of Fig. 1 shows that, in general, the carbon absorption is the function of the temperature, but this is not always the case as will be seen by the first column where the temperature of series one parallels the carbon absorption of series two and vice versa.

18. This work, therefore, verifies the opinion held by most of the investigators that the carburization practically all occurs in the cupola between the time of melting and the time of its exit from the bottom of the melting zone, in other words, the condition and temperature of the coke in the melting zone is the only item of primary importance in carbon pick-up.

19. That carbon pick-up increases with a rise in temperature may be seen in Fig. 2. The lines through the points plotted are merely approximations, but show a decided slope even so. Only two heats failed to conform to this rule, one with high tuyeres and one with low tuyeres. A possible explanation may be that, since

Table 2-A

DATA OF EACH LADLE OF EACH HEAT—SERIES 1

Heat No.	Kind Coke	Ladle No.	Melt. Temp.	Composition of Iron C Per Cent	Si Per Cent	S Per Cent	Mn Per Cent	P Per Cent
Continuous Flow—Tuyeres 4 in. Above Sand Bottom								
1.	Fdry.	3		2.80	1.34	....	....	....
		4		2.62	3.10	....	....	....
		5	1512°C	2.34	1.93	0.091	1.15	0.16
		6	2754°F	2.26	1.69	....	....	....
		7		2.05*	1.41*	....	....	....
			Average	2.51	2.01	0.091	1.15	0.16
2.	Ptrl.	3		3.23	2.29	....	....	....
		4		3.02	2.22	....	....	....
		5	1524°C	2.67	2.42	0.141	1.47	0.16
		6	2775°F	2.62	2.34	....	....	....
			Average	2.88	2.34	0.141	1.47	0.16
3.	Ptch.	3		3.15	2.25	....	....	....
		4		3.32	1.62	....	....	....
		5	1536°C	2.95	1.57	0.069	1.17	0.17
		6	2797°F	3.06	1.05	....	....	....
			Average	3.12	1.61	0.069	1.17	0.17
Continuous Flow—Tuyeres 16 in. Above Sand Bottom								
4.	Fdry.	3		2.69	1.99	....	....	....
		4		2.64	2.23	....	....	....
		5	1536°C	2.38	2.31	0.092	1.82	0.18
		6	2797°F	2.51	1.20	....	....	....
			Average	2.52	2.01	0.092	1.82	0.18
5.	Ptrl.	3		3.58	1.48	....	....	....
		4		3.12	2.16	....	....	....
		5	1524°C	3.07	1.97	0.130	1.20	0.15
		6	2775°F	2.89	1.22	....	....	....
		7		2.96*	1.70*	....	....	....
			Average	3.17	1.71	0.130	1.20	0.15
6.	Ptch.	3		3.49	1.28	....	....	....
		4		3.10	2.11	....	....	....
		5	1530°C	2.86	2.09	0.063	1.38	0.18
		6	2786°F	2.76	1.17	....	....	....
			Average	3.01	1.81	0.063	1.38	0.18

*Not in Average.

(*Continued*)

Table 2-A (Continued)

Heat No.	Kind Coke	Ladle No.	Melt Temp.	Composition of Iron C Per Cent	Si Per Cent	S Per Cent	Mn Per Cent	P Per Cent
7.	Fdry.	3		2.69	1.49	....	....	....
		4		2.03	1.14	....	....	....
		5	1518°C	2.17	3.19	0.081	1.06	0.24
		6	2764°F	2.00	1.67	....	....	....
			Average	2.22	1.89	0.081	1.06	0.24
Intermittent Flow—Tuyeres 16 In. Above Sand Bottom.								
8.	Fdry.	3		2.71	2.50	....	....	....
		4		2.53	2.21	....	....	....
		5	1542°C	2.41	2.26	0.100	1.54	.21
		6	2808°F	2.34	2.06	....	....	....
		7		2.38*	1.60*	....	....	....
			Average	2.50	2.26	0.100	1.54	0.21
9.	Fdry.	3		2.18	2.23	.....	....	....
		4		2.34	2.89	.....	....	....
		5	1530°C	2.25	2.24	0.092	1.61	0.20
		6	2786°F	2.19	2.28	.....	....	....
		7		2.15*	2.21*	.....	....	....
			Average	2.24	2.41	0.092	1.61	0.20

* Not in Average.

Table 2-B

DATA OF EACH LADLE OF EACH HEAT SERIES 2

Heat No.	Kind Coke	Ladle No.	Melt. °C	Temp. °F	Composition of Iron C %	Si %	S %	Mn %	P %
Continuous Flow—Tuyeres 4 In. Above Sand Bottom.									
10.	Fdry.	1	1398	2548	2.57	1.98	....	....	....
		2	1492	2718	2.66	2.11	....	....	....
		3	1524	2775	2.71	2.09	0.053	0.47	0.29
		4	1600	2912	2.83	2.15	.....	....	....
		5	1576	2869	2.74	2.09	0.054	0.48	0.26
		6	1584	2883	2.85	2.29	.....	....	....
		7	1560	2840	2.59	2.02	.....	....	....
		Average	1533	2791	2.71	2.10	0.054	0.48	0.28
Continuous Flow—Tuyeres 16 In. Above Sand Bottom.									
11.	Fdry.	1	1530	2786	2.92	2.08	.....	....	....
		2	1394	2541	3.02	2.23	.....	....	....
		3	1492	2718	2.96	2.22	.....	....	....
		4	1518	2764	3.00	2.27	.....	....	....
		5	1530	2786	2.88	2.18	0.066	0.45	0.20
		6	1536	2797	2.75	2.16	.....	....	....
		7	1524	2772	2.61	1.95	.....	....	....
		Average	1503	2737	2.88	2.15	0.066	0.45	0.20

(*Continued*)

Table 2-B (Continued)

Heat No.	Kind Coke	Ladle No.	Melt. °C	Temp. °F	Composition of Iron C %	Si %	S %	Mn %	P %
12.	Fdry.	1	1390	2534	2.73	2.02	.....	....	....
		2	1440	2624	2.80	2.02	.....	....	....
		3	1460	2660	2.86	2.06	.....	....	....
		4	1492	2718	2.90	2.12	.....	....	....
		5	1512	2754	2.76	2.03	0.071	0.46	0.23
		6	1484	2703	2.75	2.12	.....	....	....
		Average	1463	2665	2.80	2.03	0.071	0.46	0.23
Intermittent Flow—Tuyeres 4 In. Above Sand Bottom.									
13.	Fdry.	1	1518	2764	3.20	2.39	.....	....	....
		2	1554	2829	3.10	2.20	.....	....	....
		3	1584	2883	3.27	2.33	0.067	0.46	0.32
		4	1600	2912	3.11	2.25	.....	....	....
		5	1592	2898	3.04	2.29	0.060	0.46	0.30
		6	1576	2869	3.01	2.25	.....	....	....
		7	....		3.10	2.29	.....	....	....
		Average	1571	2860	3.11	2.28	0.064	0.46	0.31
Intermittent Flow—Tuyeres 16 In. Above Sand Bottom.									
14.	Fdry.	1	1390	2534	2.75	2.25	.....	....	....
		2	1460	2660	2.91	2.25	.....	....	....
		3	1468	2674	2.89	2.14	.....	....	....
		4	1506	2743	2.97	2.12	.....	....	....
		5	1518	2764	2.95	2.15	0.062	0.48	0.21
		6	1512	2754	3.05	2.18	.....	....	....
		7	1518	2764	3.01	2.15	.....	....	....
		Average	1482	2700	2.86	2.18	0.062	0.48	0.21
15.	Fdry.	1	1420	2588	2.77	2.00	.....	....	....
		2	1436	2617	2.77	1.99	.....	....	....
		3	1484	2703	2.84	2.04	0.062	0.48	0.26
		4	1518	2764	2.95	2.13	.....	....	....
		5	1542	2808	3.02	2.15	0.059	0.46	0.28
		6	1506	2743	3.08	2.19	.....	....	....
		7	1524	2775	3.08	2.21	.....	....	....
		8	1518	2764	2.96	2.12	.....	....	....
		Average	1494	2720	2.93	2.10	0.061	0.44	0.27

both heats showed close to their saturation points in carbon, increased speed of melting shortened the time of contact with the incandescent coke.

20. The contact of the melted steel with the incandescent coke

is doubtless affected by the degree of tenacity with which the slag clings to the pieces of coke after each tap, and the reluctance of the slag to release its mantle of protection about the coke and float back to the surface of the melted steel in the well. Thus a highly viscous slag will tend to produce a lower carbon pick-up while a cupola is operated with intermittent flow, all other factors being equal. During operation with continuous flow, the conditions are only slightly changed. The fluid slag falls through the melting zone and envelopes the coke, protecting it from contact with the steel, and using the heat of the steel to force the slag to release its mantle from about the coke. Loss of the superheat of the steel will tend to produce a lower carbon pick-up during the same time of contact.

DETAILS OF CUPOLA AND ITS OPERATION

21. Since there has recently been considerable interest in the operation of small cupolas, we have added an appendix giving exact details of the practice followed in this investigation.

ACKNOWLEDGMENT

22. The authors wish to express their appreciation to Messrs. R. H. Elder and R. E. Deas, chemists of the American Cast Iron Pipe Co., who analyzed all of the specimens.

APPENDIX

DETAILS OF PRACTICE IN OPERATION OF SMALL CUPOLA

1. *Description of Cupola*

The cupola used for experimental work is a portable type (Fig. 3) with blower, motor and stack all mounted on a small steel bodied car. The shell is 31 in. in diameter, lined to 21 in. with fire clay brick. The lining is straight from mantle to top. Before each heat the lining is checked and maintained cylindrical by daubing with small fire brick fragments and fire clay. Air is introduced through two tuyeres, 4½ in. in diameter, and blast is supplied by a No. 4 Champion Blower and Forge Co. fan type blower. The height of the stack from mantle to top is 6 ft., and an extension, fire brick lined, increases this height to 8 ft.

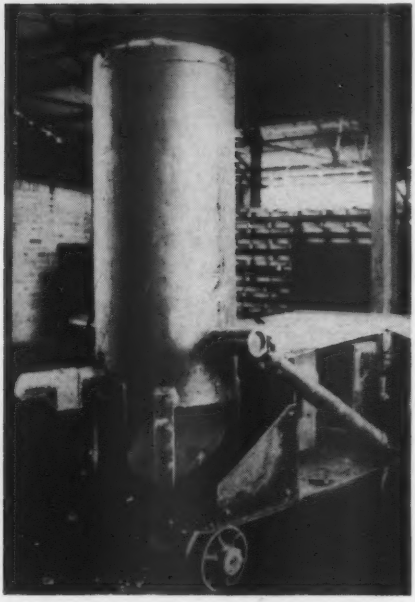

FIG. 3—PORTABLE CUPOLA.

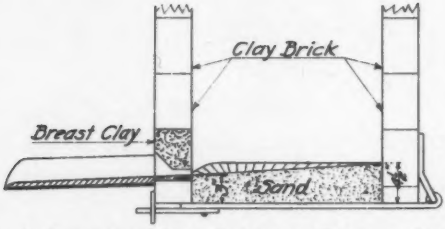

FIG. 4—DETAILS OF SAND BOTTOM OF PORTABLE CUPOLA.

2. *Bottom Sand*

The sand used to ram the bottom is coarse molding sand, containing about 12 per cent clay and 3 to 5 per cent moisture. This sand is rammed high around the walls and in the back of the furnace, sloping towards the tap hole, see Fig. 4. This height of sand on the walls and in the center is checked with a long rod, and measurements kept constant for each heat.

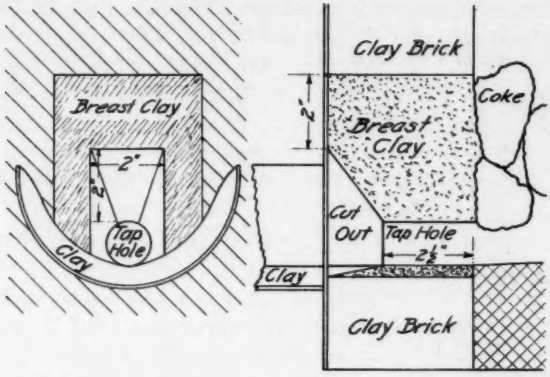

FIG. 5—DETAILS OF BREAST AND TAP HOLE OF PORTABLE CUPOLA.

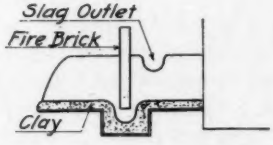

FIG. 6—SLAG SKIMMER FOR CUPOLA SPOUT.

3. *Coke Bed*

The size of the lumps for the bed coke are in the neighborhood of from 3 in. to 5 in. lumps. The coke is lighted with excelsior and wood in the usual manner. The weight of excelsior used is about 6 lb., and about 75 lb. of wood are placed on top of this. About 250 lb. of coke are charged on the wood, and as the excelsior and wood burn away, some 35 lb. more of coke are needed to build the bed to 40 in. above the tops of the tuyeres. After this coke has burned to a bright cherry red, about 40 lb. of green coke are added to give a bed of 50 in. above the tuyeres. The metal charges are placed on this last coke.

4. *Ramming the Breast*

The opening in the shell for the breast is 4 in. wide and 5¾ in. deep. Sufficient small pieces of coke are introduced in this opening against the bed coke to give a firm base against which to ram the breast clay. A ⅞ in. diameter bar for intermittent flow, and 1¼ in. diameter for continuous flow, is laid on the clay lining of

the trough with one end against the bed coke in the breast hole. Clay, containing about 45 per cent Montgomery red clay, 10 per cent moisture and 45 per cent sharp sand, is packed over and around the bar by hand, then a small rammer is used to pack the clay tightly into the breast hole. The degree of hardness with which the clay is packed will depend on the moisture and clay content of the breast clay. After ramming the clay, a slick is used to cut away part of the clay to leave a groove for the bod to slide into, as shown in Figure 5. The bar is loosened and removed, and the tap hole dried for about 20 minutes.

When continuous flow is used, the tap hole is larger, but the preparation is the same as that for intermittent flow. The trough, however, is equipped with a skimmer, that removes the slag from the iron. This skimmer arrangement is illustrated in Fig. 6.

5. *Method of Operation*

After the bed has been burned to 40 in., the breast rammed in and the bed then built up to 50 in. with green coke, the metal is charged. Wind is then blown into the cupola for 10 minutes with the tap hole open. Blowing is discontinued, and the tap hole filled with blackening slightly moistened with water, or, in case trouble results from using water, kerosene, and a small clay bod is placed in position with the fingers. The cupola is charged to the top and blowing resumed. After some 10 or 12 minutes more, the cupola will be ready to tap. A ladle, previously heated to a very bright red, receives the iron for whatever purpose it is intended.

In the tests described in this paper the cupola was kept full of coke until the iron was all melted. For routine operation, this is expensive and the blast should be eased off, as the level of material falls in the stack, to preserve the normal melting rate until the end of the heat.

DISCUSSION

MEMBER: In this study was any attempt made to differentiate between the types of carbon that might exist in the individual cokes, as for instance, in using a petroleum or pitch coke?

DR. MACKENZIE: No, I assume the condition of the carbon is the same in all of them. We were just using commercial coke.

MEMBER: The point I have in mind is that in the case of a pitch or petroleum carbon, there must be some difference because there is some difference, of course, in the volatile content.

DR. MACKENZIE: As to that point, the volatile content of the pitch coke is very little higher than the foundry coke. It only runs about 0.6 per cent and the foundry coke will be between 0.5 and 0.6 per cent usually, sometimes running up to 0.7 per cent. The volatile content of the petroleum coke was, I think, around 3 or 4 per cent. We used it all up before we thought of making an analysis on it. But the fixed carbon is shown by the absolute difference in the pitch as against the foundry coke. It only carburized to 2½ per cent, whereas the pitch coke produced near 3 per cent, and the petroleum even went up as high as 3.1 per cent. So that proved there is a difference in the coke, but I do not think you will find the reason for it in the atomic structure, or any molecular change.

CHAIRMAN M. KUNIANSKY[1]: You think the change is entirely physical?

DR. MACKENZIE: Yes. Those two cokes will have less than 0.4 per cent ash and the other coke will run 9.5 per cent.

G. P. PHILLIPS[2]: A few years ago, we changed from intermittant tapping on a 20 per cent steel mixture to a continuous flow from the cupola and the difference in carbon, averaged over a long period of time, was almost nothing.

R. S. MACPHERRAN[3]: The pickup of carbon in the cupola due to coke would seem to depend upon several factors: characteristics of coke, time of exposure to, as well as the temperature of, the melted iron, amount of coke, and especially the amount of fresh surface exposed. Naturally one would expect less of a pickup, other things being equal, in a cupola with a continuous tap than one with intermittent tapping and consequently a repeated exposure of the iron to the coke bed. There is usually a greater pickup at the first part of the heat. In fact, after a large amount of iron has gone through the cupola, the surface of the coke in the bed (below the tuyeres) would tend to become encrusted and a small carbon pickup would be expected.

We found that on taking out our top row of tuyeres, we had a drop in our carbon pickup. The same occurred when we reduced the number of pounds of coke on the bed. Following the natural line of thought, one would expect a greater total pickup from a low carbon charge and a lower percentage pickup in a charge already almost saturated. There may be modifications in the above due to varying conditions but I believe in general we may expect the pickup to follow opportunity and natural laws of solution.

CHAIRMAN KUNIANSKY: We find in running an all-steel heat of 60 or 50 tons, that we may start with the first iron with 3.10 per cent carbon, with the coke of 93 per cent fixed carbon, and a real high bed and toward the end of the heat, we would probably finish up with a total carbon in the metal of around 2.60 or 2.75 per cent. That is in spite of the fact that we quit charging, reverse the burden in the cupola, cut our blast down.

DR. MACKENZIE: When you start with an all-steel heat, the coke in the bed is clean so you get good contact. For instance, in our mix where

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[2] Metallurgist, International Harvester Co., Chicago, Ill.
[3] Chief Chemist, Allis-Chalmers Mfg. Co., Milwaukee, Wis.

we use about a 15 per cent steel and get a 3.50 per cent total carbon. We put on, say 45 in. of the bed and then a couple of thousand pounds of steel, put on 10 in. more coke and then start the regular charge (10,000 lbs.). By that means, we can keep the first iron from being too high in carbon. I do not believe there is any way of keeping the first iron from being too high in carbon in an all-steel heat without running the risk of getting cold iron. It is better to arrange to use a little higher carbon iron than it is to try to fix it.

MEMBER: What effect does temperature have on carbon pickup in the cupola?

DR. MACKENZIE: There is a chart in the paper (Fig. 2) which shows the carbon goes up quite consistently with the temperature.

H. RAYNER[4]: I would like to ask if you have any figures on the length of time the iron was held in the well? The whole problem revolves itself around the carbon pickup. Is that pickup in the combustion zone or is it in the well? We have a problem where, when the cylinder line stops, we may have, say, 5 tons of iron in the well and the question is, how long can we hold that iron in the cupola well without getting into the danger zone of high carbon? Sometimes it is necessary to hold the iron in the cupola until it is just barely possible to pour it due to the temperature drop. Then we have to take that iron and put it into the electric furnace. If we have high carbon, of course, the electric furnace takes care of it. How long can we hold the iron in the well and still make a satisfactory casting?

DR. MACKENZIE: Absorption is a function of temperature and time of contact, so anything you do to keep the metal in contact with carbon and keep it hot will cause that much more absorption. The amount of absorption will depend upon each kind of coke and how much coke you have in the well, etc.

MR. RAYNER: In our practice, we would assume the temperature was the same and the coke was the same, so the time would be the only element bearing on it.

DR. MACKENZIE: It would depend upon time and upon how well the metal is in contact with the carbon. If it is in contact with slag you would not get any absorption but if the coke is clean and in contact with the metal, you will absorb carbon.

MR. RAYNER: The coke would be clean since it is continuous operation with back slagging.

DR. MACKENZIE: You will have equilibrium conditions depending on the temperature.

MR. RAYNER: The answer then would be, the longer the iron is held in the well the greater the carbon absorption.

[4] Foundry Metallurgist, Chrysler Corp., Detroit, Mich.

Sand Castings of Copper-Silicon Alloys

By H. A. Bedworth* and V. P. Weaver,** Waterbury, Conn.

Abstract

The copper-silicon alloys are comparatively new copper-base alloys in which copper is hardened and strengthened by the addition of silicon plus other elements. Sand castings of these alloys are tough, strong, and corrosion-resistant; their application is increasing where these properties plus desirable fabricating qualities make them the most logical and economical material to use. Castings are made in brass foundries using standard equipment and methods with which foundrymen are familiar in the casting of gun metal and other bronzes. In general, the alloys are supplied in the form of ingots for remelting and the use of deoxidizers is not necessary. The more important points in the correct foundry practice include melting in a neutral or slightly oxidizing atmosphere, pouring without turbulence, and control of freezing to avoid shrinkage defects. Other precautions more or less common to the casting of copper alloys involve control of pattern design, pouring temperature, quality and moisture content of molding sand, freedom from contamination by other metals, attention to correct charging procedure and handling of scrap. Violation of any of the principles of good foundry practice usually is made evident by corresponding defects and, on the other hand, the nature of the alloys is such that correct procedure results in excellent castings suited to many purposes. Details of cleaning, finishing, and machining indicate the alloys to be adaptable to the production methods of foundries handling other copper alloys. For various reasons the copper-silicon alloys have been found to be more desirable materials to fabricate and use than many of the other copper alloys.

1. The increasingly widespread use of copper-silicon alloys in many important fields of industry has made necessary an understanding of their casting technique in the non-ferrous foundry. The

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present paper will describe the methods used in the production of copper-silicon alloy sand castings and indicate that this comparatively new group of alloys is responsive to application of the various well known fundamental principles of foundry practice. An outline will be given covering the melting, molding and pouring of the alloys, followed by a brief summary of their properties and uses.

2. Metallurgists have devoted much time and study to the possibility of substituting other metals for tin in the older and better known bronzes. The copper-silicon group is an outstanding example of this development brought about by a decrease in the world's visible supply of tin and the high price of this metal.

3. The alloys are principally copper alloyed with the element silicon plus one or more additions to enhance their other properties, particularly those which render them especially suitable for the manufacture of castings. Silicon, one of the most abundant elements on the surface of the earth, occurs mainly in the form of its oxide, silica, or as a constituent of silicates, these forms being more familiarly known as sand or rock. Commercially pure silicon is reduced from these compounds.

4. Castings of copper-silicon alloys are specified by the U. S. Navy Department in its specification 46B28 and by the Federal Specifications Board in its specification QQ-C-593, the chemical composition requirements of which are as follows:

	Per cent
Silicon	1.00-5.00
Manganese (Max.)	1.50
Zinc (Max.)	5.00
Iron (Max.)	2.50
Tin (Max.)	2.00
Impurities (Max.)	0.50
Copper	Remainder

5. The important alloying agent is silicon which enters into solid solution with copper and hardens and strengthens it at a rate much faster than the common metals such as nickel, zinc, tin, and aluminum. The metallography of some of the alloys is described by Smith.[1, 2] Although a wide range of composition is permitted by the Government specifications and the silicon limits are espe-

[1] Smith, C. S., *"The Constitution of the Copper-Silicon System,"* TRANS. A.I.M.E., Institute of Metals Div. (1929), p. 414.

[2] Smith, C. S., *"Alpha-Phase Boundary of the Ternary System Copper-Silicon-Manganese,"* TRANS. A.I.M.E., Institute of Metals Div. (1930), p. 164.

cially broad, the alloys which are supplied for foundry use contain usually from about 3.5 to 4.5 per cent silicon. Because of the great hardening power of silicon, the wider limits of Government specifications would permit alloys of greatly varying physical properties and the minimum physical requirements of the specifications have therefore been set at 45,000 lb. per sq. in. tensile strength and 15 per cent elongation in 2 in.

6. The development of the alloys has proceeded under patent protection and the marketing has been carried on through the use of proprietary names. The authors of the present paper have had experience principally with the nominal formula 95 per cent copper, 4 per cent silicon, 1 per cent manganese, which has been in commercial use for sand casting for the past 10 years.

Melting Practice

7. Copper-silicon alloys come to the foundryman in notched ingot form ready for use and can be melted and cast with the regular equipment of brass and bronze foundries. The use of deoxidizing agents is not necessary during the melting to produce good castings.

8. The alloys are successfully melted in crucible furnaces, fired with anthracite coal, coke, oil, or gas, or in electric furnaces. It is advantageous to maintain a neutral or slightly oxidizing atmosphere. The presence of a reducing atmosphere brought about by insufficient air supply, causing incomplete fuel combustion, results in a tendency for the alloys to absorb unburnt furnace gases which thereupon are expelled while freezing of the metal takes place. Spewing and gas porosity are almost certain to be the result.

9. To protect the metal during melting it is usually recommended that a layer of some gasless flux be used such as ordinary bottle glass. While it is possible to use charcoal as a cover, it is not considered advisable because of the strong tendency of charcoal to absorb moisture and gases which, if not burned, may cause porosity in the alloy.

10. The alloys are melted in a quick fire and not exposed to contact with the flames any more than necessary. Molds should be prepared in advance to insure taking the metal from the furnace as soon as the proper temperature is reached and the metal should not be allowed to remain in the furnace too long after reaching the pouring temperature.

11. Crucibles used are of graphite or a clay-graphite mixture.

12. Excessive stirring or puddling during the melting is to be avoided as this is not necessary; it tends to disturb the protecting cover and may cause contamination of the metal by furnace gases.

Charging

13. In ordinary practice, the charge will consist of about 50 per cent new ingot and 50 per cent remelt in the form of gates, risers, etc. With the correct melting conditions and the use of some ingot with each charge, it is not necessary to replenish the constituents of the alloys by additions of alloying elements. The ingot metal is charged first, together with enough glass for the cover and after this is melted down the scrap is added. Foundry scrap should be reasonably free from dirt and molding sand. Care is taken that scrap is not allowed to be exposed to the furnace flame and then permitted to melt and trickle down through harmful gases. Such a procedure will cause absorption of reducing gases if these are present or, on the other hand, excessive oxidation and loss of metal if an oxidizing atmosphere exists.

14. Machine shop scrap in the form of turnings, borings, shavings, etc., can be successfully used in the charge. This type of scrap, however, should be kept dry and, preferably, free from oil or similar cutting compounds. Because of the high ratio of surface to volume in such scrap, oxidation and gas absorption must be kept at a minimum by melting down the material at a low temperature in a bath of molten metal.

15. Contamination of the charge by other foundry alloys is to be rigorously avoided by maintaining a close control over scrap handling and setting aside the required melting equipment such as crucibles or furnaces for such alloys.

MOLDING

16. The copper-silicon alloys are a very fluid and searching type of metal which makes it possible to run small castings of thin sections producing sharp and well defined outlines. The molding in general would follow quite closely the practice for gun metal.

Sand Practices

17. For these alloys, a fairly open sand will give the best results. The wide variety of castings for which the alloys have

been used makes it rather impractical to suggest any one sand for all purposes. Sand of about No. 0 Albany Grade is successfully used for lighter sectioned castings and No. 1 or 2 Albany is used for heavier sectioned castings. The moisture content should not be more than 5 or 6 per cent. For best results, particularly on heavier sectioned castings, baked molds are used.

Cores

18. Cores should be made from an open, sharp sand with, preferably, linseed oil for a binder. The ratio of sand to oil is about 60 or 70 of sand to 1 of oil and should be high enough to give an open and fairly soft core. Baking should be at 350 to 500° F. for at least several hours and the cores may then be given a wash.

Ramming

19. The molds should not be hard-rammed close to the pattern but in the body of the mold away from the pattern the ramming can be somewhat harder. The permeability of the sand is improved by light ramming; it is also desirable that every chance be given the sand to contract in order to counteract hot-shortness during freezing and so lessen the danger of shrinkage cracks. There should also be vents to aid the escape of gases.

Gating

20. Although there are a number of fundamental principles to be observed in gating, probably the most important is that every pattern is a problem in itself and should be treated as such. In general, the metal should enter the mold cavity near the bottom and with the least amount of splashing and turbulence. Gates are preferably placed at the heavier sections where it is possible to use feeding risers which will contain the hottest metal when pouring has been completed.

Strainer Gates

21. For some castings, a good method is to pour through a strainer gate that can be choked quickly. The runner leading from the strainer should be cut considerably larger than the combined area of the holes in the strainer in order to reduce the pressure between the strainer and the casting. Fig. 1 illustrates the appli-

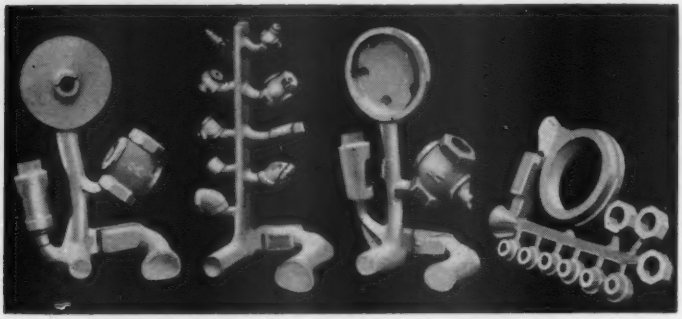

FIG. 1—METHOD OF GATING SMALL CASTINGS WITH STRAINERS AND LARGE RUNNERS.

cation of strainer gates for small castings. It will be noted that runners are made quite large and therefore act as feeders during freezing.

By-Pass Gating

22. Some foundrymen prefer to use a by-pass and runner for pouring the copper-silicon alloys. The by-pass is placed in the drag of the mold and is cut deeper than the runner. The runner may be placed entirely in the cope or at the parting of the flask, half in the drag and half in the cope. The by-pass checks the velocity of the metal, and being cut deep, acts as a strainer, insuring clean metal entering the runner. Branch runners from the main runner to the patterns are cut either at right angles or staggered back. This acts as a further check to the velocity of the metal and assures its flowing into the mold with the least possible disturbance. Fig. 2 illustrates the by-pass method.

Shrinkage

23. The copper-silicon alloys have a moderately high shrinkage and have a freezing range that causes shrinkage of the inter-

FIG. 2—METHOD OF GATING USING THE BY-PASS.

dendritic type. This results from the first metal to freeze sending out fingers or dendrites of high melting point constituent and around these dendrites the last metal to freeze then leaves voids unless precautions are taken to feed the heavier sections with sufficient molten metal.

24. Freezing should take place progressively from the thinner sections toward the heavier sections which in turn should be fed with risers located as close to the section to be fed as is practicable. As mentioned before, feeding risers, if possible, should be located near the gates so that they may get the benefit of hot and fluid metal which has not been chilled in passing through the mold cavity. Risers should be of sufficiently large cross section so that the riser is the last metal to freeze. The height of the riser is not so important; in fact, blind risers extending only partly up through the cope are frequently used to good advantage provided they are of correct cross section.

25. For securing sound castings, particularly fittings which must be leak-proof, it is also well to make use of as much hydrostatic pressure of molten metal as possible by pouring rather hot and having high sprues either through the use of high copes or built-up sprues or pouring basins.

26. It is also quite important that generous fillets be used where the gates join the casting and where thin sections join heavier sections.

27. Inasmuch as copper-silicon alloys, when cast under proper conditions have a good surface, it is urged that small machining allowance be made wherever possible in order to take advantage, as is the case with all castings, of the hardest and soundest metal on the surface or skin.

28. In large castings where there is a long cooling period or in castings where it is impractical to feed all heavier sectioned bosses and lugs, chills are of benefit, particularly for castings subjected to pressure. The use of chills will help to secure progressive and uniform freezing toward the parts being fed.

Pouring

29. The alloys should not be poured at a higher temperature than is necessary for the metal to run satisfactorily. Castings poured at too high a temperature are susceptible to several types of defects. The alloy of 95 per cent copper, 4 per cent silicon, 1 per

cent manganese begins to freeze at approximately 1832° F. (1000° C.). Large, heavy castings of this alloy are poured at about 1950 to 2050° F. and small, light-sectioned castings are often advantageously poured as high as 2250° F.

30. The metal should be poured as slowly as is consistent with the running of the castings being made, especially in the case of large castings. The slower the pouring, the less liability there will be of scruff. For large castings, it is advisable to use a pouring basin.

31. Glass used as a cover during melting is preferably skimmed off before pouring. This is best done by thickening the glass with a handful of silica sand before trying to remove it with a skimmer bar.

CLEANING AND FINISHING

32. Castings are sometimes sand blasted before and sometimes after the removal of sprues, gates, and risers. Sprue cutters and band saws are used in trimming small castings. Hack saws, manually operated or power driven, and pneumatic chisels are used for larger castings. The castings may also be wire-brushed, pickled, or water-tumbled. Considerable expense can often be saved by a study of the most suitable saws and other equipment used in cleaning.

Machining

33. The copper-silicon alloys are readily machinable where the correct procedure is followed, and a good lubricant is used. Where a refrigerant-base oil is employed, the work must not be allowed to stand around any longer than necessary after machining in order to avoid staining. Tools should be high-speed steel with cutting angle similar to that used on brass except that turning tools should have slight top slope. Carboloy and chromium plated tools have also been used to advantage. The alloys can be machined at a speed equal to or higher than many alloys of less strength and inferior physical properties.

WELDING

34. The copper-silicon-manganese alloy is readily welded with rods or electrodes of copper-silicon-manganese alloy by oxy-acetylene and electric arc methods. This makes it possible to join the castings, by means of welding, to other fabricated parts. The

welding properties have been used to advantage by foundrymen in salvaging what would otherwise have resulted in defective or rejected castings. Blow holes, resulting from improperly vented cores or molds, or scabs, occurring in the castings, can frequently be chiseled or bored out, and then filled up by welding with rod or electrode. After machining, the salvaged casting will be as sound as if the defect had not occurred and the weld will have the same strength as the cast metal.

Heat Treatment

35. The copper-silicon-manganese alloy may be heat treated (annealed) at temperatures of approximately 1300 to 1350° F. and quenched to further toughen the metal, improve its machining qualities, remove casting strains from certain types of castings and increase the resistance to pressure.

Properties and Uses

Properties

36. The copper-silicon alloys are strong, tough, corrosion-resistant alloys having physical properties superior to the tin bronzes and possessing the fundamental corrosion resistance of pure copper.

37. The alloy of 95 per cent copper, 4 per cent silicon, 1 per cent manganese has approximate physical properties as given in Table 1.

Table 1

Approximate Properties—Copper-Silicon Alloy

Melting Point	1832° F. (1000° C.)
Specific Gravity	8.15
Weight (lbs. per cu. in.)	0.294
Pattern Maker's Shrinkage (in. per ft.)	3/16
Thermal Conductivity at 20° C. (cal./sq. cm./cm./sec./°C.)	0.06
Electrical Conductivity at 20° C. (per cent I.A.C.S.)	4.9
Brinell Hardness No. (10 mm. ball, 500 Kg. load)	80
Tensile Strength (lb. per sq. in.)	50,000
Yield Point (lb. per sq. in.) (at 0.75 per cent extension under stress)	20,000
Elongation (per cent in 2 in.)	20
Reduction in area (per cent)	25
Modulus of elasticity in tension (lb. per sq. in.)	15,000,000

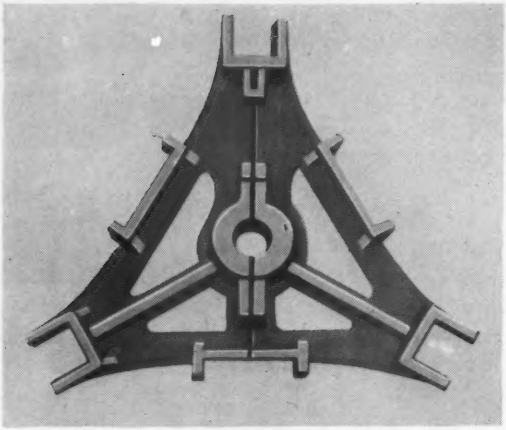

FIG. 3—THIS TYPE OF CASTING WHEN MADE OF COPPER-SILICON ALLOY IS UNUSUALLY STRONG.

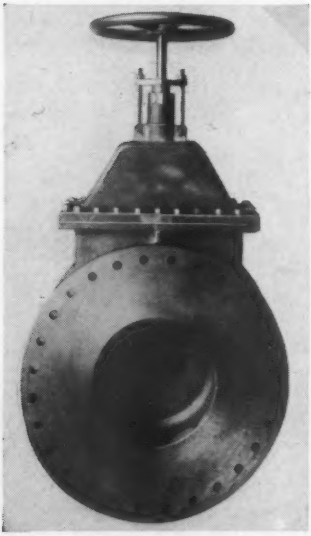

FIG. 4—16-IN. GATE VALVE OF CAST COPPER-SILICON ALLOY. WEIGHT 2,000 LB.

Fields of Use

38. The copper-silicon alloys are non-rusting and offer excellent resistance to corrosion by a large number of normally corrosive solutions and compounds. However, similar to copper and all copper-base alloys, they are not equally resistant to all corroding agents or to the same corroding agent under all conditions. Corro-

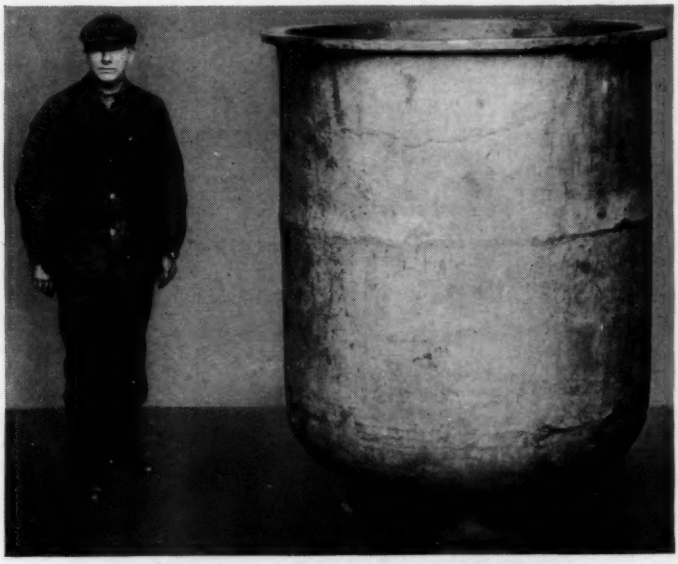

FIG. 5—CAST COPPER-SILICON ALLOY KETTLE. WEIGHT 3,440 LB.

sion may be particularly affected by the presence of oxidizing agents.

39. These alloys have been found of special value for resistance to atmospheric corrosion of all types in both industrial and marine locations and are also very resistant to corrosion by sea water as well as corrosive industrial and natural waters, to sulphuric and hydrochloric acid and many of their salts, to alkalis and many of the alkali salts. Good resistance is shown to certain organic compounds including alcohol, phenol, cresol, sugar solutions, fatty acids and organic salts.

40. The strength and toughness of the copper-silicon alloys are used to good advantage in castings of the type shown in Fig. 3. Many castings requiring such qualities coupled with good corrosion

resistance have been used in sewage disposal equipment, marine hardware, chemical process equipment and other locations. Fig. 4 shows a 16 in. gate valve weighing 2,000 lb. made of a copper-silicon alloy. A wide variety of such valves have found extensive use in highly corrosive atmospheres and liquids.

41. Figure 5 illustrates a copper-silicon alloy kettle such as used for industrial plants where a durable and corrosion-resistant metal is required. For making such a piece of equipment, good casting properties are essential. Fig. 6, showing a water wheel cast from a copper-silicon alloy, is another example of a casting

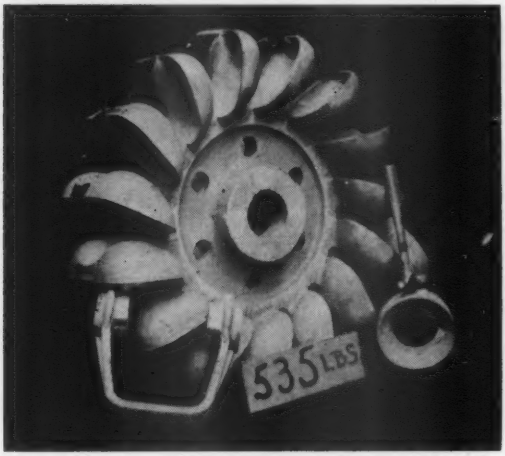

FIG. 6—CAST COPPER-SILICON ALLOY WATER WHEEL.

requiring a metal which is cast readily and has good strength and corrosion resistance.

42. Figs. 3 to 6 are indicative of the variety of uses to which the copper-silicon alloys are adapted. Some of the other applications include drain fittings, electrical conduit fittings, and transmission line connectors. The fluidity of the alloys has been used to good advantage in casting intricate centrifugal pumps.

43. The copper-silicon alloys may be expected to find greater use as the study and knowledge of their properties and service records become more widespread.

DISCUSSION

CHAIRMAN H. M. ST. JOHN[1]: The subject of this paper is a very interesting one. The alloy is not precisely new, but as non-ferrous alloys go, it is rather novel to most of us.

MEMBER: Can this alloy be welded by the same material, or is a special welding rod necessary? Can sticks be cast from this alloy so that we have the same type of welding rod?

MR. WEAVER: Yes, it is possible to cast sticks of the alloys, but it would be better to use welding rods similar to the base metals. These are readily obtained from the manufacturer or welding rod distributors and probably of better quality than sticks that might be made in the foundry. Ordinarily one can expect sufficiently better welding results to repay the cost of welding rods.

CHAIRMAN ST. JOHN: Does the alloy lend itself to soldering and is any special technique necessary?

MR. WEAVER: Yes, the alloys can be soldered but must be cleaned thoroughly to get a good bond. Refractory scale or surface film should be removed by a sodium bichromate—sulphuric acid solution or hydrochloric acid solution. Soldering is then performed in the usual way with zinc chloride flux.

J. J. CURRAN[2]: These copper silicon alloys do possess a desirable combination of strength, corrosion resistance and general usability, but it is my understanding that they do not stand up so well under rather moderate steam pressures and temperatures. It is my feeling that a word of caution ought to be included on that point. This, I believe, is the first time that this type of an alloy has been put before the A.F.A. in this manner, and since it is to go into the record, and I feel that all of the properties should be included, bad as well as good.

H. J. ROAST[3]: We have been interested in this alloy for the past three years, and it has done more for our foundry than any other alloy we have ever tackled. When one deals with a new alloy, one looks into it more, and we had a great deal of trouble with this one. I strongly object to the statement that "this is an easy alloy, just the same as any other." It is not, but on the other hand, a little patience will get good results with it.

As to Mr. Curran's remark in regard to the use of this alloy with steam, we have recommended a silicon alloy, not quite the same as that of which the writers have spoken, having iron rather than manganese, and it stands the very high pressure of the latest modern locomotive in Canada. We feel that it is well to add a word of caution when the danger is there, but suggest that perhaps this is an occasion where we do not need to "raise the flag."

One might find an easy explanation for the difficulty that has been experienced. This intercrystalline shrinkage to which reference is made is, of course, a characteristic of the alloy, and to be told what it looks like is a help. When one breaks this alloy, there is a sort of a golden

[1] Metallurgist, Detroit Lubricator Co., Detroit, Mich.
[2] Metallurgist, Walworth Co., Greensburg, Pa.
[3] Vice-President, Canadian Bronze Co., Montreal, Que., Canada.

fracture in places, only little areas here and there in a cross-section, we will say of 4-sq. in., but it is that inter-crystalline shrinkage which will, if present, cause leakage.

In regard to the pressure resistance, we have made a number of castings to check this and have used pressures of 6000 lb. per sq. in., with wall thicknesses as low as could possibly be expected from the physical constant of the metal. Of course, most will be aware that the thinner one can make a wall to resist pressure, the better off you are, because if there is any chilling effect, you have the benefit of it. But there is this to be said of silicon alloys, that you can cast 4 in. sections with no difference in appearance in the fracture from the outside to the center. There is none of that ⅛ to ¼-in. of chill effect of the sand. This is, to my mind, one of the great recommendations for this alloy.

In regard to the use of charcoal, we made the alloy for one year with charcoal, and we had trouble until the end of the year. When we threw charcoal out, we no longer had this dendritic structure and inter-crystalline shrinkage under the same conditions of feeding.

In regard to the welding, we made a number of tests by what is commonly called in the foundry "burning in" which, after all, is welding. This alloy particular lends itself to repairing a defective casting in this manner.

In regard to soldering, we have occasion to do soldering with this metal, and we follow the usual practice of cleaning the metal with hydrochloric acid and zinc and then soldering in the usual way, and we have found the bond to be thoroughly satisfactory.

CHAIRMAN ST. JOHN: Not all of these copper-silicon alloys have the same composition. There is quite a variation. Personally, I am somewhat in the dark as to what different results would be experienced from these variations in composition, and what their effect would be on the points which have been raised in this discussion.

I would like to ask Mr. Roast what type of melting equipment he used when he tried charcoal.

MR. ROAST: We have used crucible melting and direct arc electric furnaces, throwing in the charcoal as an experimental test. We also used an open flame melting furnace, a type which we do not recommend.

CHAIRMAN ST. JOHN: The charcoal was a disadvantage in all of these cases?

MR. ROAST: We could not get as good results with charcoal as without it.

I forgot to mention for the benefit of anyone who expects to use this alloy for plate work in place of 85-5-5-5, we find that we do not get satisfactory results if the patterns and gates are left unchanged. The author in his illustrations showed what I believe is the fundamental reason for getting best results—that is, the runners all placed in the cope to act as feeders.

MR. CURRAN: I do not wish to give the impression that I have anything against this alloy. I am merely looking for accuracy in the record.

Mr. Roast mentioned that the difficulty that I refer to may be due to shrinkage, interdendritic, I believe, he called it. Actually, my own

experience has been chiefly with forgings, and under the circumstances, I doubt if there was any shrinkage present.

But I think this point ought to be "aired" because it is going down in the record for people who know nothing about it, and they ought to be informed.

MR. ROAST: I think we should say this, that if a casting or a billet, from which all forgings must originate, has interdendritic or intercrystalline shrinkage, in the first place, you cannot eliminate that by any amount of forging because you have an oxidized film which also gets in, hence, the change of color, and no amount of welding will make that absolutely tight. If the casting is defective from intercrystalline shrinkage, you cannot cure it by forging.

I understand that one of the troubles is that so few people break their casting or their billet for their subsequent forgings to be sure that the fracture is right. A nice outward appearance and good tensile strength can be obtained, but if you want high pressure resistance such as 6000 lb. per sq. in., you must have uniform fractures.

MR. BEDWORTH: The point that has been raised regarding use with steam is a very good one. I would say, frankly, that we have known of cases of failure of wrought metals, that is, metals that have been rolled, sheet metals, in steam at high pressures, more particularly where they have been used under conditions of fatigue, such as expansion joints, and so on. This has led to quite conservative recommendations where the alloys are to be used with steam at high pressure. This applies more particularly to the sheet metals, which may be used under conditions where you might get fatigue or have a high stress.

On the other hand I will say that we have never experienced a case of failure of a sand-casting by steam. We have seen it in the thinner metals. As Mr. Roast has said, I think perhaps the "flag" point is well taken, but as far as castings go, from a practical standpoint, while we are still conservative in our recommendations; yet we have never seen failure of a casting in that way.

CHAIRMAN ST. JOHN: To clarify that point somewhat, Mr. Bedworth, am I correct in assuming that the difficulty which may occur with wrought metal in steam and pressure is a matter of intercrystalline corrosion?

MR. BEDWORTH: We think so. There seems to be some sort of a breakdown of steam at high pressures and temperatures. In fact, we have done quite a bit of research on that point. You can see readily that with a thin sheet the effect would be important. That is, you could have an effect that would not be particularly deep, but still it would be serious, especially if the metal is getting a mechanical movement. With castings you usually have such a heavy body of metal that a superficial effect does not really mean anything. That is, the castings "stay put" so that even if you did have a little surface effect, it would not necessarily cause any trouble.

CHAIRMAN ST. JOHN: It would also be influenced, would it not, if there were any work strains present in the wrought metal?

MR. BEDWORTH: Yes, I think so.

CHAIRMAN ST. JOHN: In other words, it partakes of the nature of season cracking, even though it might occur in strain-free metal, as a result of stress corrosion. This is something we encounter in some of the copper-zinc alloys in wrought metal, but, as you have mentioned, very rare indeed with castings.

MR. CURRAN: From what I have seen, I obtained the impression that it was an oxidation of silicon in the alloy along the grain boundaries that produced something like the growth of cast iron. As far as I know, it occurs only in special instances, but in the valve industry, every so often we have to make valves to meet such conditions.

CHAIRMAN ST. JOHN: This is a rather delicate question, Mr. Weaver, but this particular paper deals, I presume, with "Everdur" while part of the discussion has to do with PMG metal. We have also "Herculoy" and "Olympic" bronze along with one or two others which fall in the same general class.

To what extent are we talking about the same thing in speaking of these different alloys, and to what extent, in your opinion, do small differences in the composition change the performance of the alloy?

It is not my intention to enter into a long discussion of the relative merits of these alloys, but I think it is important that we should know which of these statements may be taken as general statements applying to copper-silicon bronzes as a class, and which may be open to question as a result of differences in the composition.

MR. WEAVER: Our experience has been mainly with the copper-silicon-manganese alloy, but any information we have at hand leads us to believe the general foundry practice would be the same for each one of this group of alloys. With rather wide limits for composition, there will of course be corresponding variations in the properties of the alloys

MR. ROAST: I would like to say that from the point of view of my particular company, we do not think there is any superiority of PMG over other silicon bronzes. Properly made they are all good.

J. E. RIFFER[4]: Regarding the question that arose as to the welding, I have had this experience with copper-silicon alloys. We had castings, 1700 lb. dressed, and being a rather rush job, a certain bracket on the outside was overlooked. A question arose as to how to attach it, and it was rather difficult as to who would take the responsibility if we tried to weld it on with a fluid metal. However, we tackled the job and put a bracket on the side, approximately 40 lb., and after it was machined off, they gave it every opportunity to get a tensile strength. In order to make absolutely sure, it was put into an annealing oven over night to relieve any strain or stress. Later on these castings had a steel tank welded to the bottom. These tanks had to stand oil pressure, and they are still in use without any defect. There was no trouble welding the steel on, but in our case it was a case of putting on a bracket of 40 lb. after the casting had been cleaned up. We built a mold around the casting, preheating it, and left ample space for flow-off. After we had made the bracket separately and put it to the casting, leaving a space accurately figured out, using a ½-in. rod in the joint so we could tell exactly

[4] St. Catherines Brass Works, Ltd., St. Catherines, Ont., Canada.

when both points were melting as we had left the castings 1/8-in. apart, then stopping up the flow of the metal, the castings were absolutely perfect.

CHAIRMAN ST. JOHN: Before we close this discussion, there is one question which I would like to have Mr. Weaver answer in his final summary. On page 201, under "Properties and Uses," the paper mentions that copper-silicon alloys possess the fundamental corrosion resistance of pure copper. I have seen similar statements made on a number of occasions from which one would get the impression that when we add other alloying constituents to copper, we do so solely in order to obtain superior physical properties, strength, yield point, and the like, and seldom if ever we do hope to obtain better corrosion resistance in the alloy than we had in the original copper. I wonder to what extent that is true. For example, to name a case that is more or less familiar to most of us, certainly copper-zinc in the proportion of approximately two-thirds copper to one-third zinc is far more resistant to attack by sulphur and sulphides than is the pure copper. Now with respect to other corrosive conditions, do we have in this alloy a certain superiority over what would be the case with pure copper.

MEMBER: In view of the fact that the constituents of this particular alloy are both readily oxidizable, how do the authors explain the statement that they do not need a deoxidizer? Furthermore, how do they get rid of the entrained silicates which certainly must result from the melting of this alloy if they do not require any deflux or deoxidizing?

MR. WEAVER: In regard to deoxidizing, we have not experienced difficulty with entrained silicates. The alloys are melted and poured with very little dross and fractures and microsections are quite free from non-metallic inclusions. Oxides which may be formed are removed as a fluid slag and it is not necessary to add a deoxidizer.

In regard to the corrosion resistance, I would be glad to have Mr. Bedworth discuss that a little more in detail.

MR. BEDWORTH: Perhaps I can answer that a little more fully than Mr. Weaver.

As you probably all appreciate, corrosion resistance is a very complicated subject. That is, there are many ramifications, and we have attempted only to make a brief, conservative statement which is, for all practical purposes, close enough. There are many cases where the addition of silicon does improve the corrosion resistance, but corrosion problems are more or less individual, so that we have not attempted to cover the subject in detail. We do say, generally speaking, that the corrosion resistance of the copper-silicon alloy is approximately the same as that of copper—which is good—and in many cases somewhat better.

The alloy was developed by C. B. Jacobs, prior to 1922. Mr. Jacobs, with whom I was associated until recently, when he died, developed the alloy primarily as a corrosion resistant alloy to withstand hydrochloric acid. He experimented with a great many alloys and finally arrived at this one as a very good material to withstand hydrochloric acid at different concentrations and temperatures. It was in a class by itself.

This is one specific instance of improved corrosion resistance, but

in a general way when we say that it has about the same resistance to corrosion as copper, that is a fairly accurate and practical statement.

MEMBER: I would like a little further information in regard to the heat treatment of copper silicon alloys. The authors mention here that heat treatment improves the machining and removes casting strains. I would like to know the effect of the heat treatment on the principal physical properties, the tensile strength, elongation, hardness, reduction of area. In this heat treatment, as I understand it, the castings are heated and quenched in cold water. I would like to know if that has any effect.

MR. WEAVER: With variations in the composition and heat treatment of these alloys, the metallography is quite complex. The heat treatment mentioned in the paper is essentially a homogenizing anneal which renders the copper-silicon-manganese alloy an alpha solid solution. Reduction of area and elongation are considerably increased with almost no change in hardness and tensile strength.

Heat treatment at about 450° C. (832° F.) will somewhat increase the strength and hardness with considerable loss in ductility through the precipitation of manganese silicide. Air cooling would lessen the danger of warping in quenching large castings.

The Constitution of Bond Clays and Its Influence on Bonding Properties†

By R. E. Grim,* R. H. Bray,** and W. F. Bradley,***
Urbana, Ill.

Introduction

1. The purpose of this paper is to present information concerning the constitution, particularly the mineral constitution, of various clays, and to consider the relation between the constitution of clays generally and their bonding properties. It is a well known fact that not all clays possess the same physical properties, *e.g.*, not all bond clays have the same bonding strength. It was the object of the research herein reported to investigate the fundamental causes for the differences in bonding properties possessed by different clays. An adequate understanding of durability and other properties, and the writing of satisfactory specifications for bond clays and synthetic sands, must await a knowledge of these fundamental causes.

2. These researches were part of a general project of the Illinois State Geological Survey designed to study the constitution of clays and shales and the relation between factors of constitution and properties determining their economic utilization.

Clay Minerals

3. Recent studies[1] have shown that clays are composed essentially of one or more of a comparatively small group of minerals known as the clay minerals (Table 1). They are hydrous aluminum silicates and some of them contain also alkalies or alkaline earths. The clay minerals so far investigated have a general micaceous crystalline habit, as a consequence of which their individual par-

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† Presented and published with the permission of the Chief, Illinois State Geological Survey and with the approval of the Director, Agricultural Experiment Station, University of Illinois.

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*** Asst. Chemist, Illinois State Geological Survey.

Note: This paper was presented at a session on Sand Research at the 1936 Convention of A.F.A. in Detroit, Mich.

[1] Ross, S. C., and Kerr, P. F., "*The Clay Minerals and Their Identity*," Jnl. Sed. Pet. 1, pp. 55–65 (1931); Endell, K., Hofmann, U., and Wilm, D., "*Ueber die Natur der Keramischen Tone*," Ber. deut. keram. Ges. 14, pp. 407–438 (1933); Grim, R. E., and Bray, R. H., "*The Mineral Constitution of Various Ceramic Clays*," Jnl. Am. Cer. Soc. (In press.)

Table 1

COMMON CLAY PRODUCTS

Name	Chemical Composition	Remarks
Kaolinite	$Al_2O_3.2SiO_2.2H_2O$	Anauxite and kaolinite form an isomorphous series.
Anauxite	$Al_2O_3.3SiO_2.2H_2O$	
Halloysite	$Al_2O_3.2SiO_2.xH_2O$	
Beidellite	$Al_2O_3.3SiO_2.xH_2O$	Beidellite and nontronite form an isomorphous series.
Nontronite	$Fe_2O_3.3SiO_2.xH_2O$	
Montmorillonite	$Al_2O_3.4SiO_2.H_2O$	Montmorillonite, beidellite, and nontronite probably contain essential alkalies or alkaline earths.
Sericite-like mineral	$K_2O.3MO.6R_2O_3$ $18SiO_2.5—10H_2O$	

ticles are flat and flake-shaped. The flake-shaped characteristic, however, is not developed to the same degree in all of them. This is important because many of the properties of clays are the result of the shape of their component particles.

COMMON CLAY MINERALS

4. At the present time, it is not possible to write exact formulæ for all the clay minerals—those for beidellite, nontronite and the sericite-like mineral particularly, are to be regarded as tentative. Until it can be specifically named, the sericite-like mineral is so designated because it resembles the sericite form of white mica. Future research may discover a few additional common clay minerals.

5. Clays which act differently usually are composed of different assemblages of these minerals.[2] In other words, different clays possess different properties depending on which one or more of the clay minerals they contain. Closely related to mineral composition is base-exchange which also influences the properties of clays. This will be discussed in some detail later in the paper.

MATERIALS INVESTIGATED

6. The minerals investigated include one natural bonded molding sand, three bond clays widely used in preparing synthetic molding sands, and five additional clays not used as molding sand bonds. These latter clays were selected because they represent types of clay containing a number of different clay minerals, and because certain of their physical properties, such as plasticity, shrinkage, etc., are high, suggesting that they might also have high

[2] Grim, R. E., and Bray, R. H., *Idem.*

bonding strength. Flint clays, diaspore, china clays, shales and other types well known to possess low bonding power are not included in the present report. They have been analyzed and their mineral constitution is presented elsewhere.[3] The analytical data for these materials, however, will be used in discussing the influence of mineral composition on bonding properties. Since it is the purpose of the present paper to point out the causes of differences in bonding properties of various clays and not to discuss the bonding properties of a clay from a given district, the locations of the samples studied are not given.

ANALYTICAL PROCEDURE

7. The mineral composition—particularly of the so-called colloid fractions,[4] the base-exchange capacity, the green compression strength, and the permeability were determined for each clay investigated. Also, data were obtained concerning the particle size distribution of each clay.

8. The mineral composition was determined by the procedure of Bray, Grim, and Kerr.[5] It consists briefly of (1) treatment to remove easily soluble material and exchangeable bases to permit adequate suspension of the colloid fractions; (2) dispersion and sedimentation to remove the particles coarser than one micron in diameter; (3) fractionation of the suspension containing the particles smaller than one micron by means of the supercentrifuge; (4) optical study with the petrographic microscope of the bulk sample and all fractions; (5) X-ray diffraction photography of the colloid fractions; (6) chemical analyses and base exchange capacity determinations of the bulk sample and all fractions.

9. In the analysis the material is separated into four divisions of about the following grade sizes:

Residue	R	+ 1 micron in diameter.
Coarse colloid fraction	C	1 to 0.1 micron in diameter.
Fine colloid fraction	F	0.1 to 0.06 micron in diameter.
Superfine colloid fraction	S	— 0.06 micron in diameter.

10. The procedure gives some information concerning the size grade distribution of the constituents of the clay, although its prime purpose is to fractionate the material so that the mineral constituents are isolated in sufficient purity to permit identification

[3] Grim, R. E., and Bray, R. H., *Idem.*

[4] For the purpose of description, material existing in particles smaller than 1 micron is designated in this paper as being of colloidal size.

[5] Bray, R. H., Grim, R. E., and Kerr, P. F., "*Application of Clay Mineral Technique to Illinois Clay and Shale*", BULL. GEOL. SOC. OF AM. 46, pp. 1909–1926 (1935).

by the microscopic, x-ray, and chemical data. This is essential for clays containing mixtures of minerals in the colloid fractions. Sample 8 (Table 2) represents a mono-mineral clay with a well established mineral composition, consequently fractionation was not necessary.

11. The base-exchange capacities were determined by leaching with ammonium acetate followed by a neutral alcohol wash. The replaceable ammonia was determined by distillation.

12. The tests[6] of the green compression strength and permeability were made by C. E. Schubert of the Mechanical Engineering Department of the University of Illinois. All determinations were made on mixtures of 3000 grams of standard silica sand, 145 grams of clay, and sufficient water to yield a moisture content of about 5 per cent after tempering. The sand, clay, and water were mixed in the Simpson Sand Mixer in the usual way for 7 minutes. A tempering time of 24 hours was allowed before the tests were made.

MINERAL COMPOSITION

13. The mineral compositions, Table 2, are based on a comparison[7] of the analytical data given in the appendix with similar information for pure minerals. The compositions are further summarized in Table 3, in which the relative abundance of the important constituents is estimated for each clay without reference to the particle size in which they occur.

14. The mineral analyses show that most of the clays studied are mixtures of the clay minerals in different proportions. Sample 8 composed of montmorillonite, and sample 7 in which the finest fractions are composed largely of beidellite are exceptions. The clay in the natural bonded sand (sample 9) is dominantly beidellite.

15. Sediments are known[8] which are composed mainly of kaolinite and the sericite-like mineral. Such materials, of which china clay and shale are respectively illustrative, have not been included here because of their well known low bonding strength.

16. These mineralogical data emphasize the statement that clay is not one entity in the sense that common salt is one definite substance. Because of differences in mineral constitution, clays with identical grade size distributions cannot be considered exactly

[6] *Standard and Tentatively Adopted Methods of Testing and Grading Foundry Sands*, American Foundrymens Association, pp. 33-92 (1931).

[7] Bray, R. H., Grim, R. E., and Kerr, P. F., *Op. cit.*

[8] Grim, R. E., and Bray, R. H., *Op. cit.*

Table 2

MINERAL COMPOSITION

Sample No.	Residue		Colloid[3] fractions					
			Coarse		Fine		Superfine	
1	kaolinite	VA	kaolinite	VA	kaolinite	VA	beidellite	
	white mica[1]	A	sericite-like	VC	sericite-like	VC	kaolinite	
	quartz	A						
2	quartz	A	kaolinite	VA	kaolinite	VA	kaolinite	
	kaolinite	A	sericite-like	VC	sericite-like	VC	sericite-like	
	white mica	VC	quartz	R			beidellite	
3	montmorillonite	VA	montmorillonite	[2]	montmorillonite	[2]	montmorillonite	[2]
	quartz	A						
	glauconite	R						
	white mica	R						
4	_____?	VA	_____?		_____?		_____?	
	quartz	VC						
	white mica	VR						
	glauconite	VR						
5	kaolinite	VA	kaolinite	VA	kaolinite	VA	kaolinite	
	quartz	A	sericite-like	VC	sericite-like	C	sericite-like	
	white mica	VC	quartz	R			beidellite	
							organic material	
6	quartz	VA	kaolinite	VA	kaolinite	VA	kaolinite	
	kaolinite	VC	quartz	C	sericite-like	C	sericite-like	
	white mica	R	sericite-like	C			beidellite	
7	quartz	VA	quartz	A			beidellite	
	feldspar	C	sericite-like	A				
	white mica	C	beidellite	VC				
	chloritic mica	R	kaolinite	VR				
8	This clay was not fractionated since it is composed almost entirely of montmorillonite in particles which in the main are of colloidal size or can be easily disintegrated to this size.							
9	quartz	VA	sericite-like	VA	beidellite		beidellite	
	feldspar	C	quartz	C				
	white mica	C	kaolinite	VR				
	limonite	C						

[1] White mica of the Residue fractions is so designated because it is probably a mixture of the sericite-like mineral and muscovite.

[2] X-ray data indicates the presence of a very small amount of kaolinite.

[3] VA = 40 per cent +; A = 40 per cent — 25 per cent; VC = 25 per cent — 15 per cent; C = 15 per cent — 10 per cent; R = 10 per cent — 5 per cent; VR = —5 per cent.

the same. It is not sufficient, therefore, to characterize as "clay" all material finer than a given grade size.

17. The mineral analyses of these clays (Tables 2 and 3) and other data from our researches indicate that kaolinite, the sericite-like mineral, beidellite, and montmorillonite are the most common clay minerals. Kaolinite and the sericite-like mineral

occur in most clays in particles from 0.1 micron to several microns in diameter. Occasionally they are found in smaller particle sizes, in which case there appear to be slight variations in certain of the properties of these minerals.

18. Although beidellite may occur in some clays in particles several microns in diameter, it is easily reduced in size on working so that analyses usually show it as a constituent of the finest colloid fractions. Montmorillonite, likewise, is easily reduced to extremely fine particle size.

19. Quartz varies in abundance in general with the gritti-

Table 3

MINERAL COMPOSITION SUMMARIZED

Sample No.	Mineral Composition
1	kaolinite VA; sericite-like[1] VC; quartz C; beidellite VR
2	kaolinite VA; quartz VC; sericite-like[1] VC; beidellite VR
3	montmorillonite VA; quartz VC; white mica, glauconite, and kaolinite VR
4	_____? VA; quartz C; white mica and glauconite VR
5	kaolinite VA; quartz C; sericite-like[1] C; beidellite and organic material VR
6	kaolinite VA; quartz A; sericite-like C; beidellite VR
7*a*	quartz VA; sericite-like[1] VC; beidellite VC; feldspar, chloritic mica, and kaolinite VR
7*b*	beidellite VA; quartz C; sericite-like C
8	montmorillonite VA; quartz R
9	quartz VA; beidellite VC; sericite-like[1] C; feldspar R; limonite R; kaolinite VR

a Natural raw material.

b Purified clay grade (—0.003 mm.) used in bonding determinations.

[1] Includes "White mica" of the Residue fractions of Table 2.

ness of the clay, and in size from several millimeters to about 0.06 micron in diameter. In fractions of smaller size no quartz is detected.

20. Additional investigation is necessary to specifically identify the dominant constituent in sample 4. Although its optical characters are those of montmorillonite, it differs from this mineral in its X-ray diffraction pattern and in possessing a higher silica and magnesia content. The name attapulgite[9] has been suggested for this mineral but it is not well established. Likewise, there is a possibility that the material is a mixture of montmorillonite and a hydrated magnesium sillicate mineral similar to sepiolite.

[9] de Lapparent, J., *"Sur un Constituant Essential des Terres à Foulon"*, Compte. Rendus, 201, pp. 481-3 (1935).

21. There is some suggestion from the X-ray data that the material noted as beidellite in the superfine fraction of the clays may not be identical for each clay. It is probable that there are several slightly varying forms of this mineral, all having nearly the same physical properties. Further, there is a suggestion that the beidellite in the superfine fraction of one clay (Sample 1) is finer grained than in the corresponding fraction of another clay (Sample 3). If this is the case a difference in the physical properties of the two clays would be anticipated.

22. Similarities between the diagnostic characteristics of the sericite-like mineral and beidellite in the finest colloid fractions make it difficult to differentiate them. Likewise, similarites between kaolinite and halloysite when they exist in small amounts in the finest colloid fraction make their separate identification extremely difficult. Consequently, small amounts of halloysite in the superfine fraction of sample 6 would not be detectable.

23. The silica content of the superfine fraction of sample 3 determined as montmorillonite is notably higher than the usual value for this mineral.[10] In the absence of evidence for the presence of any other crystalline mineral in this fraction, the silica content signifies either the presence of amorphous silica or that the ratio of silica to R_2O_3 in montmorillonite may vary within wide limits.

INFLUENCE OF MINERAL COMPOSITION ON GREEN COMPRESSION STRENGTH

24. It is a well known fact that such properties of clays as plasticity, shrinkage, and bonding strength vary with particle size. They tend to increase as particle size decreases. However, the data in Table 4 show conclusively that particle size alone does not control bonding strength as represented by green compression strength. For example, sample 5 with almost twice as much material below 1 micron as sample 3 possesses only 40 per cent as much green compression strength. The evidence is even more conclusive than given in Table 4, since the portion of sample 5 above 1 micron is only slightly coarser than this size, whereas the portion of sample 3 above 1 micron is much coarser than this size. Further, the data given in the appendix show that variations within the colloid size range for these samples are not of sufficient magnitude to account

[10] Hofmann, U., Endell, K., und Wilm, D., "*Kristallstruktur und Quellung von Montmorillonit*" Zeit. f. Krist. 86, pp. 340-348 (1933).

for their different compression strengths. Other examples supporting this conclusion could be drawn from the analytical data.

GREEN COMPRESSION STRENGTH AND PERMEABILITY

25. Since texture alone does not account for the variation in bonding strength of clays other factors for it must be sought. A comparison of Tables 3 and 4 shows that bonding strength varies with the mineral composition. Clays with high green compression strength are composed largely of montmorillonite or beidellite. These facts and others, not herein presented, lead to the general conclusion that, other factors being equal, increasing amounts of these two minerals increase the bonding properties of a clay. The

Table 4

GREEN COMPRESSION STRENGTH AND PERMEABILITY

Sample No.	Amount of clay below 1 micron in per cent	Moisture in per cent	Green compression strength in lb./in.^{2}	Permeability in per cent
1	48	4.9	0.8	90
2	46	4.8	0.9	95.4
3	39	5.0	2.3	100
4	68	5.2	2.7	95
5	72	4.8	1.0	85
6	50	4.8	.8	93.4
7*	80	5.0	2.8	91.1
8	95	4.9	3.4	88

*These determinations were not made using the bulk natural material, but with the clay fraction, *i. e.*, all sand and silt coarser than about 0.003 mm. were removed from the original sample before it was used.

reasons for this are the inherent structure (lattice) of the minerals and their tendency to break down more easily than other clay minerals into extremely minute colloidal sized particles. The disintegration may take place gradually as the clay is worked so that its maximum bond strength is not released until it is worked more than once.

26. Other factors being equal, clays containing kaolinite possess lower bonding properties than those made up of beidellite or montmorillonite. Similarly materials composed of the sericite-like mineral will possess less bonding strength than those containing kaolinite. On the basis shales, china clays, flint clays, etc., would not be expected to serve as bond clays since they are composed almost entirely of the sericite-like mineral and kaolinite, respectively.

27. The green compression determinations in Table 5 were obtained with the water values listed which are not necessarily

Table 5

BASE EXCHANGE CAPACITY AND GREEN COMPRESSION STRENGTH

Sample No.	Exchange capacity* in m. e. per 100 gm.	Green compression strength in lbs. per sq. in.[2]
2	10.4	0.9
5	13.0	1.0
1	14.4	0.8
6	17.5	0.8
4	27.0	2.7
3	45.0	2.3
7	57.0	2.8
8	82.0	3.4

*These determinations were made on the clay actually used in making the green compression strength determination. To obtain the capacity of the sand and clay mixture, these values must all be multiplied by the percentage of clay in the mixture, i. e., 4.6 per cent.

optimum values for the mixture of clay and sand used. For certain clays the mixtures tested were too wet for the development of maximum green compression strength, for others they were too dry.[11] A correlation of this information with the mineral composition of the clays shows that those composed largely of montmorillonite or beidellite were in general too dry to show maximum green strength and that the others were too wet indicating that the optimum moisture content for clays composed largely of montmorillonite or beidellite is higher than it is for clays composed of the other clay minerals. With optimum moisture content the relative green compression values for clay minerals as constituents of bond clays are the same as given above. The conclusion that bond strength increases with the content of montmorillonite or beidellite is, therefore, unaltered.

BASE-EXCHANGE

28. The importance of base-exchange[12] for ceramic clays has recently been emphasized.[13] It has been shown that certain properties of clays are related to the amount and nature of the exchangeable ions present.

[11] Schubert, C. E., Personal Communication.

[12] Base-exchange phenomena can be visualized by reference to a zeolite or permutite water softener. Water is hard because it contains calcium compounds popularly called "lime." As hard water passes through the zeolite softener, the calcium of the water is exchanged for sodium which the zeolite originally contained, i. e., sodium goes from the zeolite to the water in exchange for calcium which goes from the water to the zeolite, thereby softening the water. Passing a salt solution through the softener reverses the process reviving the softener. Clays possess this property to a lesser degree than zeolites.

[13] Endell, K., Hofmann, U., and Wilm, D., "*Ueber die Natur der Keramischen Tone*," Ber. deut. keram. Ges. 14, pp. 407–438 (1933). Grim, R. E., and Bray, R. H., "*The Mineral Constitution of Various Ceramic Clays*," JNL. AM. CER. SOC., In press.

29. The base-exchange capacity of a clay resides in its clay mineral constituents, and different clay minerals possess different exchange capacities. Opinions differ as to whether the exchangeable bases are held on the surface of the colloidal clay mineral particles or within their lattice structure. Likewise, opinions differ as to whether base-exchange is a stoichiometrical chemical reaction or is simply adsorption. The exchange capacity for montmorillonite is high, for beidellite it is moderately high, and for kaolinite and the sericite-like mineral it is very low or nil.

BASE EXCHANGE CAPACITY AND GREEN COMPRESSION STRENGTH

30. In regard to bond clays, data in Table 5 show that green compression strength increases with an increase in the base-exchange capacity of the bonding clay. The complete significance of base-exchange on the constitution and properties of clays is not yet entirely clear. Certain aspects warrant consideration. Since beidellite and montmorillonite have much higher exchange capacities than the other clay minerals, their relative abundance in a clay should be reflected by this value, *i. e.*, high base exchange capacity reflects large amounts of these minerals, and hence high bonding strength. Other factors, however, must also be considered. These indicate that only an approximation of bonding strength is to be hoped for by computation from base-exchange capacity. In the first place, the probable variation of exchange capacity with particle size of a specific mineral also must be considered. In the second place, bonding properties are influenced by the character of the exchangeable base present in a clay. Thus two clays identical with respect to their mineral composition, texture, and exchange capacity, may be expected to show slightly different bonding properties if they possess different exchangeable bases.

31. It is known that certain physical properties of clays vary according to whether sodium, calcium, hydrogen, or some other cation is present as the exchangeable ion. The fact that the addition of acids or alkalies causes the physical properties of clays to vary has been known for some time, but only recently has its fundamental cause—base exchange—been elucidated. As a means of controlling and improving the properties of certain clays, this subject is of great importance and one deserving careful additional research. Obviously it can play an important role only in clays with a high exchange capacity, *i. e.*, in beidellite or montmorillonite clays.

EFFECT OF HEAT ON CLAY MINERALS

32. Clays are altered when subjected to heat which, in very general terms, is the reason why molding sands deteriorate when used. Since not all clay minerals alter at the same temperature or at the same rate, information concerning their behavior when heated is important in understanding molding sand durability.

33. Montmorillonite is dehydrated gradually up to about 1022°F (550°C)[14] at which temperature crystallographic changes begin. Following treatment of the mineral at lower temperatures, rehydration takes place and the original characteristics are retained. The few data[15] on beidellite at elevated temperatures suggest that it reacts like montmorillonite.

34. Kaolinite loses little water below about 752°F (400°C).[16] Almost all of its moisture is lost between 752 and 950°F (400 and 510°C) as shown by the steep slope of the dehydration curve between these temperatures. Schachtschabel[17] has shown that after heating to as low as 392°F (200°C), kaolinite regains its water very slowly at ordinary temperatures and pressures, and that after heating to 806F° (430°C), it rehydrates very slightly.

35. No information on the rehydration characteristics of the sericite-like mineral is available. Its dehydration curve[18] however, possesses certain similarities with that of kaolinite.

36. The red to yellow hydrated ferric oxides, collectively designated here as limonitic material, which occur prominently in some natural molding sands, lose practically all their moisture below about 392° F (200°C).[19] Following heating to this temperature there is very slight rehydration of the material on cooling.

37. The products obtained when clay minerals are heated above their transformation temperatures are fairly well known.[20] In general terms, they are various forms of Al_2O_3, various forms of SiO_2, mullite, glass, etc., depending on the original material and the temperature. Of utmost importance is the fact that these

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[14] Hofmann, U., Endell, K., und Wilm, D., "*Kristallstruktur und Quellung von Montmorillonit*", Zeit. f. Kristallographie, 86, pp. 340-348 (1933).

[15] Larsen, E. S., and Wherry, E. T., "*Leverrierite from Colorado,*" Jnl. Wash. Acad. of Sci. 7, pp. 208-217 (1917).

[16] Ross, C. S., and Kerr, P. F., "*The Kaolin Minerals,*" P. P. 165-E, U. S. Geol. Surv., 1931.

[17] Schachtschabel, P., "*Uber Dehydratisierung und Rehydartisierung des Kaolins*", Chem. d. Erde, 4, (395-419) 1930.

[18] Grim, R. E., "*Petrology of the Pennsylvanian Shales and Non-calcareous Underclays Associated with Illinois Coals*", Bull. Am. Cer. Soc. 14 (1935).

[19] Posnjak, E., and Merwin, H., "*Hydrated Ferric Oxides,*" Am. Jnl. of Sci. 47, pp. 311-348 (1919).

[20] A voluminous literature exists on this subject. See "*Notes on the X-ray Diffraction Patterns of Mullite.*" E. Posnjak, and W. Greig, J. Am. Cer. Soc. 16, pp. 569-583 (1933).

derived constituents are not flake-shaped[21] and, therefore, no longer possess one of the attributes causing plasticity, green strength, etc., in materials containing them.

38. The reason for the deterioration of molding sand is thus evident, and two molding sands should not be expected to deteriorate at the same rate or to the same degree, even when heated to the same temperature, unless their mineral constitutions are the same. Durability must, therefore, take into consideration the clay minerals making up the clay.

CONCLUSIONS AND SUMMARY

39. (1) Clays are composed of one or more of a group of minerals known as the clay minerals which are essentially hydrous aluminum silicates together with alkalies or alkaline earths. Different clays vary from each other in the character and relative abundance of the clay minerals which they contain.

(2) Clays with the same appearance and the same size distribution of composing particles will possess different physical properties such as bonding power, durability, etc., if they are composed of different clay minerals. It is impossible, therefore, to set up one series of arbitrary tests for all clays regardless of their mineral composition. Unless such tests are based on constitutional factors, confusion will result.

(3) Clays composed primarily of beidellite or montmorillonite have higher green compression strength, higher optimum moisture content, and possibly better durability characteristics than those composed of the other clay minerals. Stated another way, smaller amounts of beidellite or montmorillonite clays than of other clays are required to provide equivalent bond strength in a synthetic molding sand. Additional research is needed, particularly to determine the influence of specific clay minerals on other physical properties important in bond clays.

(4) On the basis of the relation between mineral composition and bonding properties, it is possible to predict with considerable accuracy the bonding properties of a given clay from its mineral composition as determined by a petrographic analysis. Since the chemical compositions of the clay minerals are much the same, an ultimate chemical analysis alone is usually not sufficient to indicate the mineral composition of a clay.

[21] For a recent discussion of this point, see E. O. Wilson, "*The Plasticity of Finely Ground Minerals with Water*", Jnl. Am. Cer. Soc. 19, pp. 115–120 (1936).

(5) In approximate terms, clays having high base-exchange capacity also have high bonding strength. The relation between these, however, is not precise, because they both are influenced by particle size, and bonding strength is also influenced by the identity of the exchangeable base present in a clay.

(6) The physical properties of clay vary depending on whether sodium, calcium, hydrogen, or some other cation is present as the exchangeable ion. Additional research is needed to determine the exact influence of specific exchangeable bases on clays of known constitution. This factor can play an important role in controlling the properties only of clays composed largely of beidellite or montmorillonite since the other clay minerals contain low or no base-exchange capacity.

(7) At elevated temperatures, the clay minerals are transformed to other substances which possess different physical properties, and, therefore, no longer yield plasticity, green strength, etc., to materials containing them. Since a given amount of heat influences different clay minerals at different rates and to different degrees, the deterioration of a bond clay will depend on its mineral constitution.

(8) It is recognized that much additional research is essential to an understanding of all the factors involved in the bonding properties of clays and natural molding sands. The data herein presented emphasize the conclusion that such research must take cognizance of the mineral composition of the material.

APPENDIX

ANALYTICAL DATA

Sample No.	1				2			
Fractionation†	R	C	F	S	R	C	F	S
SiO_2	61.09	47.15	46.62	45.24	67.61	47.79	46.78	45.17
Al_2O_3	26.50	37.73	36.99	32.21	18.85	35.29	34.17	32.08
Fe_2O_3	1.17	0.93	1.30	1.78	1.92	1.03	2.84	1.99
FeO	0.26	0.24	0.33	0.78	0.46	0.59	0.62	.....
MgO	0.71	0.86	0.87	1.00	0.20	0.59	0.81	1.40
CaO	0.15	0.07	0.18	0.16	0.20	0.47	0.51	0.33
Na_2O	0.03	0.06	0.06	0.13	0.48	0.48	0.25	.....
K_2O	1.13	0.94	1.12	2.02	0.93	1.41	1.74	.....
TiO_2	1.37	1.16	1.00	0.90	1.00	1.37	1.26	.....
Loss on Ign.*	7.53	11.53	12.24	16.40	8.33	11.44	11.62	14.99
Total	99.94	100.67	100.71	100.62	99.98	100.45	100.60	95.96
H_2O+	7.44	11.66	12.20	12.96	7.09	11.14	11.25	.....
H_2O-	0.42	0.95	1.18	3.90	0.67	1.12	1.53	2.98
SiO_2/R_2O_3	3.80	2.09	2.09	2.30	5.66	2.26	2.21	2.30
Inorganic base exchange capacity**	8.0	12.5	26.1	31.7	4.3	15.3	20.4	28.7
Optical Data		Aggregates β=1.575 $\gamma-\alpha$=.015	Aggregates β=1.580 $\gamma-\alpha$=.025	Aggregates β—1.580 $\gamma-\alpha$=.025		Aggregates β—1.572 $\gamma-\alpha$=.012	Homogeneous aggregates γ=1.586; (—) $\gamma-\alpha$=.022; 2V small	Homogeneous aggregates γ=1.585; (—) $\gamma-\alpha$=.020; 2V small
X-ray Data		kaolinite S sericite-like W	kaolinite S sericite-like W	beidellite kaolinite		kaolinite S sericite-like W quartz W	kaolinite S sericite-like W	kaolinite sericite-like
Per cent of total clay	52	33	10	5	54	33	6	7

*The loss on ignition values for 3 and 4 are based on air dried samples. The loss on ignition values for the other samples are based on samples dried at 110° C. (230° F.).

†R, C, F and S refer to Residue, Coarse Colloid Fraction, Fine Colloid Fraction and Superfine Colloid Fraction.

**In milliequivalents per 100 grams.

S—strong lines in diffraction pattern; W—weak lines in diffraction pattern; VW—very weak lines in diffraction pattern.

Chemical analyses of samples 1, 2, 5, 6 and 9 were made under the supervision of O. W. Rees, Associate Chemist, Illinois State Geological Survey; of samples 3 and 4 were made under the supervision of R. H. Bray.

APPENDIX—*continued*

Sample No.	3				4			
Fractionation†	R	C	F	S	R	C	F	S
SiO_2	66.12	60.78	55.12	60.78	61.94	60.53	55.03	54.86
Al_2O_3	14.41	16.08	18.10	13.18	9.65	12.22	10.24	11.59
Fe_2O_3	6.73	8.83	8.70	5.86	3.49	3.68	3.53	4.43
FeO	....	....	....	....	....	....	....	....
MgO	1.27	1.54	2.39	1.92	7.84	6.81	10.49	8.51
CaO	0.06	0.21	0.27	0.50	....	0.07	....	0.18
Na_2O	....	....	....	....	....	....	....	....
K_2O	1.65	1.40	1.21	0.65	1.12	1.98	0.47	0.56
TiO_2	....	....	....	....	....	....	....	....
Loss on Ign. *	9.58	11.48	14.49	16.23	15.91	14.46	20.25	19.63
Total	99.82	100.32	100.28	99.12	99.95	99.75	100.01	99.76
H_2O+	5.09	6.10	6.82	5.95	8.04	7.27	10.13	9.52
H_2O-	4.26	4.87	6.42	8.07	7.69	6.52	9.73	9.21
SiO_2/R_2O_3	6.00	4.75	3.96	6.10	8.85	7.05	7.48	6.46
Inorganic base exchange capacity **	43	57	76.6	78	21	19.4	21	40
Optical Data		Aggregates β=1.540 $\gamma-\alpha$= .030	Homogeneous aggregates γ=1.550 $\gamma-\alpha$= .030	Homogeneous aggregates γ=1.550; (—); $\gamma-\alpha$= .030; 2V small		Aggregates γ=1.540 $\gamma-\alpha$= .032	Homogeneous aggregates γ=1.540; (—); $\gamma-\alpha$= .032; 2V small	Homogeneous aggregates γ=1.545 $\gamma-\alpha$= .032; (—); 2V small
X-ray Data		montmorillonite S kaolinite W	montmorillonite S kaolinite W	montmorillonite		————?	————?	————?
Per cent total clay	61	22	5	12	32	9	25	34

*The loss on ignition values for 3 and 4 are based on air dried samples. The loss on ignition values for the other samples are based on samples dried at 110° C. (230° F.).

†R, C, F and S refer to Residue, Coarse Colloid Fraction, Fine Colloid Fraction, and Superfine Colloid Fraction.

**In milliequivalents per 100 grams.

S—strong lines in diffraction pattern; W—weak lines in diffraction pattern; VW..very weak lines in diffraction pattern.

Chemical analyses of samples 1, 2, 5, 6 and 9 were made under the supervision of O. W. Rees, Associate Chemist, Illinois State Geological Survey; of samples 3 and 4 were made under the supervision of R. H. Bray.

APPENDIX—*continued*

Sample No.	5				6			
Fractionation †	R	C	F	S	R	C	F	S
SiO_2	65.70	47.19	45.05	42.65	....	48.10	47.08	49.34
Al_2O_3	20.95	35.96	36.52	32.44	....	37.24	36.35	33.85
Fe_2O_3	0.40	0.85	1.15	1.64	....	1.47	1.85	1.96
FeO	0.20	....	....	....	....	....	....	....
MgO	0.37	0.59	0.64	0.67	....	0.84	1.12	0.98
CaO	0.31	0.28	0.24	1.21	....	0.25	0.23	0.16
Na_2O	0.13	0.02	0.14	0.15	....	0.06	0.07	0.09
K_2O	1.27	0.92	0.87	1.37	....	0.76	0.83	1.30
TiO_2	1.69	1.39	0.91	2.00	....	....	....	0.57
Loss on Ign. *	9.18	12.48	14.13	18.10	....	12.02	12.30	12.10
Total	100.20	99.68	99.13	100.23	....	100.74	99.83	100.35
H_2O+	7.31	12.44	13.68	15.07	....	12.21	12.09	11.21
H_2O-	0.62	1.84	2.91	4.68	....	2.46	2.77	7.09
SiO_2/R_2O_3	5.26	2.20	2.06	2.14	....	2.14	2.14	2.38
Inorganic base exchange capacity **	10.3	15.5	31.0	31.0	6.8	23.5	33.7	56.9
Optical Data		Homogeneous aggregates γ=1.565 $\gamma-\alpha$= .010	Aggregates γ=1.570 $\gamma-\alpha$= .013	Aggregates γ=1.575 $\gamma-\alpha$= .020		Aggregates γ=1.570 $\gamma-\alpha$= .010	Aggregates γ=1.570 $\gamma-\alpha$= .010	Aggregates γ=1.570 $\gamma-\alpha$= .020
X-ray Data		kaolinite S sericite-like VW	2V small kaolinite S sericite-like VW	2V small kaolinite sericite-like		kaolinite S quartz W	kaolinite S sericite-like W	kaolinite sericite-like
Per cent of total clay	28.0	57	11	4	50	36	8	7

*The loss on ignition values for 3 and 4 are based on air dried samples. The loss on ignition values for the other samples are based on samples dried at 110° C. (230° F.).

†R, C, F and S refer to Residue, Coarse Colloid Fraction, Fine Colloid Fraction and Superfine Colloid Fraction.

**In milliequivalents per 100 grams.

S—strong lines in diffraction pattern; W—weak lines in diffraction pattern; VW—very weak lines in diffraction pattern.

Chemical analyses of samples 1, 2, 5, 6 and 9 were made under the supervision of O. W. Rees, Associate Chemist, Illinois State Geological Survey; of samples 3 and 4 were made under the supervision of R. H. Bray.

APPENDIX—*continued*

Sample No.	7				8	9			
Fractionation†	R	C	F	S		R	C	F	F
SiO_2	....	....	....	....	64.60	90.63	47.85	45.50	44.92
Al_2O_3	....	....	....	....	20.80	5.39	27.07	25.81	26.03
Fe_2O_3	....	....	....	....	3.05	0.95	10.32	9.80	9.97
FeO	....	....	....	....	0.46	0.35	0.34	0.34	0.11
MgO	....	....	....	....	2.30	0.44	1.16	1.48	1.40
CaO	....	....	....	....	0.53	0.50	0.14	0.38	0.25
Na_2O	....	....	....	....	2.60	0.28	0.07	0.03	0.41
K_2O	....	....	....	....	0.40	0.54	1.51	0.83	0.29
TiO_2	....	....	....	....	0.15	0.31	1.49	0.60	0.42
Loss on Ign. *	....	....	....	....	4.74	0.67	10.35	15.40	16.34
Total	....	....	....	....	99.63	100.06	100.30	100.17	100.15
H_2O+	....	....	....	....	4.74	0.68	....	15.44	....
H_2O-	....	....	....	....	8.00	0.11	3.55	3.68	4.18
SiO_2/R_2O_3	....	....	....	....	4.81	....	2.43	2.41	2.36
Inorganic base exchange capacity **	1.2	38.3	....	71.1	82	1.3	33.5	40.7	44.3
Optical Data		Aggregates β=1.570 $\gamma-a$= .020		Homogeneous aggregates γ=1.570 (—); $\gamma-a$= 0.30 2V small	γ=1.533 (—) $\gamma-a$= 0.33 2V small		Aggregates β=1.595 $\gamma-a$= .020	Homogeneous aggregates γ=1.590 (—); $\gamma-a$= .030 2V small	Homogeneous aggregates γ=1.590; (—); $\gamma-a$=.030; 2V small
X-ray Data		quartz sericite-like kaolinite VW		beidellite	montmorillonite		sericite-like S quartz W kaolinite W	beidellite	beidellite
Per cent of total clay	75	6	5	12	100	90	5	3	2

*The loss on ignition values for 3 and 4 are based on air dried samples. The loss on ignition values for the other samples are based on samples dried at 110° C. (230° F.).

†R, C, F and S refer to Residue, Coarse Colloid Fraction, Fine Colloid Fraction, and Superfine Colloid Fraction.

**In milliequivalents per 100 grams.

S—strong lines in diffraction pattern; W—weak lines in diffraction pattern; VW..very weak lines in diffraction pattern.

Chemical analyses of samples 1, 2, 5, 6 and 9 were made under the supervision of O. W. Rees, Associate Chemist, Illinois State Geological Survey; of samples 3 and 4 were made under the supervision of R. H. Bray.

DISCUSSION

CHAIRMAN R. F. HARRINGTON[1]: Mr. Grim and his associates have made a very splendid contribution to our scientific knowledge of bonding clays and their influence on bonding properties.

DR. H. RIES[2]: Dr. Grim has given us a very interesting paper with a mass of details in it which will take time to digest. It, however, illustrates one thing, and that is how matters which seem to be of purely scientific interest sometimes turn out to be of considerable practical value. Up to the present, only petrographers have been interested in minerals in clay. They occur as very minute grains of microscopic size difficult to determine under the microscope, and yet it is possible to do so. Dr. Grim has brought out, in a rather interesting way, that these mineral particles undoubtedly seem to have an effect on certain important physical properties of clay, whether it is clay the brick maker is interested in, or clay that the foundryman uses as a bond.

I should be interested to see him carry out this work and apply it to a larger series of clays than I understand he has done at the present time. He is showing us what is possibly the cause of the characteristic behavior of some of these materials.

I would like to ask him about one point that he mentioned, namely, the effect of certain mineral ingredients of clay on its durability. The subject of durability is something that we all have heard much about. Foundrymen all talk about it and say there is no doubt that one clay may show greater durability than another. One of our sub-committees has been trying to find some method, laboratory method, by which we can determine in advance the durability of a molding sand or a bonding clay which is used in a synthetic sand mixture. Several different methods have been suggested and, in a recent piece of work that has been done at the University of Illinois, I believe the different methods were tried but, if I remember correctly, according to the diagrams they plotted the results were not the same. I would like to ask Dr. Grim whether, in expressing an opinion on the durability of a clay or a sand, he checked it up with some one particular method for determining the durability or whether he tried to strike an average?

DR. GRIM: My statements on durability were drawn from the properties of the minerals when subjected to heat. The exact relation between these properties and the durability characteristics of the molding sand will take more study. Our work was designed to investigate the mineral constituents and to determine how their properties, in the case of durability, should influence the durability characteristics of the clay. My own opinion is that there is a close correlation between the durability of a synthetic molding sand and the composition of the clay that is used as the bond. I believe the evidence points definitely in that direction but I doubt if we are ready yet to say we have the final answer to much of the problem.

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[1] Hunt-Spiller Mfg. Corp., Boston, Mass.
[2] Technical Director A.F.A. Committee on Foundry Sand Research, and Head of the Department of Geology, Cornell University, Ithaca, N. Y.

The Scaling of Steel Castings

An open discussion of this subject was conducted at a meeting on "Steel Founding" under the chairmanship of John Howe Hall, Technical Assistant to the President, Taylor-Wharton Iron & Steel Co., High Bridge, N. J., at the 1936 Detroit Convention of A.F.A.

GEORGE BATTY[1]: When a symposium on the cleaning of steel castings was first proposed, I suggested that it would be interesting to throw the meeting open for a discussion on the prevention of scaling in the annealing or heat treating operations which are normally conducted upon steel castings. This suggestion was made because I had found, in the course of my work with a number of relatively small foundries, that some of them were entirely unaware of the large losses in which they became involved as a result of excessive scaling of light steel castings, annealed or heat treated along with castings of a heavier type.

In any regularly existing set of conditions with respect to temperature, furnace atmosphere, and time, the proportion of weight of metal lost by the removal of scale is a function of the relation of total area to weight. It is, therefore, obvious that light section castings suffer a greater proportionate loss by descaling than do heavier section steel castings.

A number of tests were made on batches of castings of different types annealed or normalized at the same time and it was found that, in one foundry where the atmosphere control was not good, a scaling loss of approximately 2 per cent occurred on castings of a lumpy type averaging 50 to 60 lb. each in weight. Such a figure cannot be considered good but is indicative of poor atmosphere control. Small castings, of what might be considered a flimsy type with section thicknesses averaging little more than ¼-in., showed a scaling loss of between 8 and 9 per cent.

This presents quite a serious picture in that the production costs per pound on the light section castings was appreciably greater than that involved on the simpler, heavier section, castings. The destruction of wealth, therefore, was very much greater on the light section castings than on the heavier castings. (In using the word "wealth" I have in mind Dr. Ripper's definition: "Wealth may be considered as anything that can be converted into cash.")

Atmosphere control is something of which the producer of steel castings should very definitely take notice in order that inordinate destruction of wealth may be avoided. The temperature at which the atmosphere must be controlled varies for different types of metal and time is also a factor interacting with atmosphere in controlling the degree of oxidation or scaling of steel castings.

The heat treatment of steel castings has been considerably stressed in

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[1] Consultant on Steel Castings, Drexel Hill, Pa.

NOTE: This paper was presented at a session of the Steel Division at the 1936 Convention of A.F.A. in Detroit, Mich.

recent years to such extent that nearly all steel castings are given some form of heat treatment, and I believe that we have too readily accepted the prescription because many steel castings of a light type and of uniform or fairly uniform section thickness are heat treated and subsequently tumbled or sand blasted to remove the heat treatment scale. Such light, uniform-sectioned, castings may, in many cases, safely be put into service without heat treatment. Composition and section thickness, plus uniformity of section, are the governing factors in relation to the ability of such castings to meet their service conditions adequately. The type of casting I have particularly in mind is one having a maximum section thickness of not more than ⅜-in. produced in the ordinary carbon range 0.18 to 0.25 per cent with 0.60 to 0.80 per cent manganese and approximately 0.35 per cent silicon. Such castings may readily be tested by those of you who are interested in the proposition by putting them in a vice and beating them with a hammer, or by putting them under a press and squeezing them. I venture to believe that many of you will be surprised at the ductility of such light section castings in the unheat-treated condition.

Because of the speed of solidification, such castings are of a refined grain structure very similar to that produced by a normalizing treatment in heavier section castings and it is very doubtful whether such castings are materially improved by a simple annealing or normalizing.

Complexity of design on such light castings introduces a variable and where mold resistance or core resistance to solid contraction is an inevitable concomitant of design, the castings would obviously need a heat treatment to minimize residual contraction strains. By eliminating the heat treatment procedure on certain types of light section castings the manufacturer may avoid the expense of heat treatment and the following expense of descaling such castings. At the same time, the loss of weight by descaling is also avoided. There seems no reason why an intelligent inquiry into the service conditions to be imposed upon certain types of castings should not warrant the maker in securing the production economies indicated.

C. E. SIMS[2]: I believe it is safe to say many light steel castings, very rapidly cooled, have a considerable degree of toughness and would be perfectly serviceable for uses to which they are put without any heat treatment whatever. However, there are many cases now where heat treatment is so well established that I believe the customer would object rather strenuously if he were furnished untreated castings. I suppose in the last analysis, the criterion for the judgment of a casting should be serviceability; and if the casting will stand up perfectly and serve the purpose without annealing, annealing logically is a wasted effort. I do not believe any general statements can be made on that question. One would have to judge each casting on the basis of its design and on the uses to which it could be put.

MAJOR R. A. BULL[3]: The comment made by Mr. Batty reminds me of some tests with which I was very familiar 7 or 8 years ago, including a considerable number of relatively small steel castings ranging in weight

[2] Battelle Memorial Institute, Columbus, Ohio.
[3] Consultant on Steel Castings, Chicago, Ill.

from perhaps a couple of pounds up to 50 or 60 lb. They probably averaged about 25 lb., which represents about the average casting size in many electric steel foundries. Tests were made to determine the loss in weight by scaling, and this was very accurately determined, the sand, etc., being carefully removed. As I recall it, the average loss in weight was about 2.5 per cent.

That was the result of using an oil fired annealer. Incidentally, among the plants that were cooperating in this investigation were two which had, and still have, electric annealers. I have never convinced myself, after seeing a good many electric annealers, that electric annealing is productive of any lighter scale than can be produced in a well-constructed, well-regulated oil or gas annealer. This is contrary to the expectations of the electric annealer people when they exploited their furnaces in the first place.

Reverting to the need of annealing that Mr. Batty has mentioned and to which Mr. Sims has referred, as Mr. Sims truthfully said, the actual serviceability demonstrated by the material should be the criterion. I am thoroughly convinced from that particular standpoint, that with light and moderate sections, with what we would call, in steel foundry parlance, a low carbon rather than a medium carbon (in other words, around 0.18 to 0.21, or 0.22 per cent), and with average contents of manganese and silicon, such material does not need to be annealed to make it entirely serviceable for such severe service as that to which rolling stock is subjected.

The reason I say that is because for a period of about 12 years, I had the major operating responsibility for the production of something like 375,000 tons of steel castings that were put into railroad service, which never went into an annealing oven. Among all the castings that were made in that plant—and are still being made in that plant in the same manner—there was never a casting that came back, during my term of employment because of failure in fair service. On the other hand, a number of very interesting castings did come back to the plant described in letters from the railroads, which were very badly distorted as the result of wrecks and are now placed in the exhibit yard of that particular plant to show the superior resistance to fracture of that material.

That illustrates one of several factors that are involved in this whole question of annealing scale. Another factor that has not been as yet mentioned is, what on the whole is the best method of removing scale?

I happen to be personally of the opinion that it will not be many years before the more progressive small steel casting plants will have discarded their tumbling barrels altogether and will have resorted entirely to blasting equipment; and, incidentally, using metallic abrasives instead of sand, not entirely from the standpoint of health hazards (keeping silicosis, of course, in mind), but maintaining the nice outline you can get on a good steel casting if you use a high grade facing sand. It is foolish to spend a lot of money for that kind of molding treatment and then obliterate fine detail by the punishment the casting gets in a tumbling barrel.

CHAIRMAN J. H. HALL[4]: Major Bull's last remarks remind me of some stainless steel I once made with smooth surfaces, by use of special molding materials. Someone put them in the shot blast, using shot about five times as course as my facing sand, and the last state of those castings was worse than the first, a nice pebbled appearance.

Some years ago we were all very much interested to know whether electric furnaces did better in reducing scale losses than fuel fired furnaces. I am going to ask Mr. Sampson to tell us a little about what he knows about that.

J. M. SAMPSON[5]: I cannot say that I know exactly. We use electric annealing furnaces for larger castings, and oil-fired for smaller castings. I do not know that we ever made an accurate check, but judging from the time required to shot blast and clean a certain area, I would imagine there is not much difference in the scale.

There are other factors, however, to be considered. There is the matter of temperature control in all parts of the furnace, particularly necessary for important castings of certain compositions. We would hesitate about using oil-fired furnaces under these circumstances.

F. A. MELMOTH[6]: Referring to the heat treatment of castings 20 years ago or a little more, thousands of tons of light steel castings were sent out from English foundries without any treatment whatever. I am of the opinion they were extremely good castings. They stood up and appeared to do the job for which they were intended. But I do not think things are standing still. I am reminded of a statement made in connection with an earlier paper. The speaker wondered if all the cost of improvement was reflected sufficiently in the product and worth the original cost of making the investigations. These things are changing all the time and the demand on steel castings is changing perpetually. I cannot think of any steel foundryman who is competent to know sufficient about all the castings he puts out, and their service conditions to say definitely that untreated steel castings are generally satisfactory. We know that tests from the viewpoint of strength only give similar results both in the normalized and as-cast conditions in the very soft steels Major Bull speaks of, but in other types of tests, such as the impact tests, they certainly do not give anything approaching the test results obtained by properly heat treated or even normalized steel castings.

May I revert one moment to the question of scale? I cannot see any reason why electric heat-treatment furnaces should give less scale than any other type of furnace. It appears logical that the whole matter depends upon the tightness of the furnace and the control of the atmosphere inside of it and not the source of heat.

Figures have been given representing definite percentages of loss by scaling. That also is no good, excepting as it refers to the specific cast-

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[5] Foundry Engineer, General Electric Co., Schenectady, N. Y.

[6] Vice-President, Detroit Steel Casting Co., Detroit, Mich.

ings. There are no two types of castings in our shop or any of yours, that have the same ratio of surface to mass. There is no similarity at all. Consequently, the amount of loss is dependent purely and simply on the amount of surface in relation to the weight of the casting, other conditions being equal. I would not know how to arrive at any figure unless one were to take the whole output of the shop. I want to say I believe every steel casting, as a precautionary measure, bearing in mind the competitive situation and the ignorance with which it will probably be used and what will happen to it afterwards, should be subjected to some form of heat treatment.

MAJOR BULL: In the shop I spoke of, we had to set a dead line, so to speak, which was 0.23 per cent carbon. In other words, all material that did not exceed 0.23 per cent carbon was considered safe to ship without any annealing, but that was the top limit. The manganese averaged around 0.65 or 0.70 per cent. I do not believe the carbon content that is typical of ordinary carbon steel castings used for most miscellaneous purposes, say around 0.27 or 0.28 per cent, would be suitable for shipment without at least a normalizing treatment. I think the carbon content is an extremely important factor, and that the size of sections is also important.

MR. SIMS: This matter of composition in relation to annealing, of course, is a very pertinent one. If any castings at all should be put into service unannealed, they should be of very low composition. No casting that could remotely be called an alloy steel casting should ever go out of the shop unannealed for any kind of service. Of course, there are lots of castings that go through the furnace that are not annealed, too.

In regard to the scaling loss, I do not have any figures to cite, but I will venture to say that temperature control might be as important as atmosphere control. I would estimate that a difference of 100° or 150° might make a difference of 100 per cent in the scale that will form on a casting. I know that an increase from 1600° F. to 1700° F. will make an important difference in the amount of scale that forms. It is my opinion that extremely high temperatures are seldom justified metallurgically.

CHAIRMAN HALL: If we follow the A.S.M.'s recommendation, to heat important castings to 1700° F. or 1800° F. as a preliminary step in heat treatment, the scale loss will be high.

MR. BATTY: If the temperature demand rises, the scaling will also be increased in specific conditions of atmosphere. I want to take issue with Mr. Melmoth. I was fairly specific in defining the composition range and the types of castings to which I had particular reference in my statement that certain steel castings would not need heat treatment to fit them adequately for service. In such classification may be put quite a large number of steel castings that have been produced in recent years to replace malleable iron castings. This is not to say that all castings which are turned over from malleable to steel should not be annealed; some wise discretion must necessarily be exercised in the prescription. I would say that I have made a large number of castings to replace malleable and for these have used a steel with 0.16 per cent carbon as a maximum, a content of approximately 0.85 per cent manganese and a silicon content of the normal 0.30 to

0.40 per cent. Because of the relatively low carbon of the steel produced in the acid electric furnace, fluidity was high and without getting the melt dangerously hot—so hot that there would be considerable mold erosion or burning on of the sand—the flimsy castings could be run perfectly. Such castings were quite adequate in service and were excellently ductile.

It is probable that because of their initial fine grain they were of good impact value. Such an assumption is warranted by numerous tests with a hammer on castings held firmly in a vice. I certainly would not recommend that our low alloy castings be sent into service without a proper heat treatment nor would I suggest that the higher carbon steel castings should not be heat treated. But I do recommend, where the service conditions of the castings are known and where uniformly light section castings are produced, that the founder can save money by adopting a proper composition and the elimination of the heat treatment process which, as applied to such castings, is wasteful.

These definitions are specific and must be applied to the specific instances. They should not be translated into any recommendation that heat treatment is something we can do without. I do not think there is any stronger advocate than I, not even Mr. Melmoth in his most dogmatic moments, for the proper heat treatment of steel castings in order that the properties of the metal may be developed to their highest potentiality to meet the increasingly onerous specifications demanded by inspection authorities and certain unofficial prescription writers.

CHAIRMAN HALL: The Chair would like to ask for information in the case of these very light castings that may be shipped without annealing. Does air cooling of the castings after they are shaken out of the sand help the toughness or are they all right if they are cooled dead slow in the sand?

MAJOR BULL: It was our regular practice to make, as most steel foundries do, separately cast test blocks, of the ordinary keel block type. We made a good many tests to see what would happen from the standpoint of the factor mentioned. Of course, it was impossible to determine the true stress resistance of commercial castings that were shaken out black and those shaken out red hot. But I was never able to trace any relationship between that cooling treatment and the one-in. square coupons on a keel block that was about 4-in. thick. We got comparable ductility, yield points, and tensile strength in each case. I do not think that applies to all compositions, by any means. This steel averaged about 0.19 per cent carbon.

P. E. MCKINNEY[1]: Major Bull has talked about castings with limits of composition. I think in his opening remarks he referred to light castings. There has been too much stressing of the question of composition and too little as to the cross-section or regularity of cross-section of the casting. It would be unfortunate if we went away from this meeting with the idea that any of us would condone the putting into service of a massive, heavy casting without annealing even though the carbon content was con-

[1] Metallurgical Engineer, Bethlehem Steel Co., Bethlehem, Pa.

siderably lower than 0.19 per cent, in fact, any carbon content that it was practical to produce in a carbon steel casting.

I have in mind castings like tremendous mill housings and the heavier, massive castings used on bridges, where there are other factors than the physical properties that you might get in a test bar that came into play. The rate of solidification is very much slower than with the thin casting; the internal, pent-up stresses are such that some of those castings having odd or irregular shapes really cannot be safely dressed up and machined without danger of breaking them in half unless previously annealed. I think that will apply regardless of composition or carbon content, simply as a result of unrelieved cooling strains from that heavy mass of metal. We should pretty definitely distinguish between massive and light castings when we are talking about the safety of unannealed products.

Behavior of Cupola Refractories Under Severe Conditions

By John Lowe*, Muskegon, Mich.

Abstract

In the opinion of the author, while much information has been acquired during the past years with regard to melting, very little has been written about cupola refractories. The author states that with all-around cooperation, what are considered severe operating conditions today, may be considered normal in the future. He gives what may be the ideal in cupola operation of the future and gives several cases which he considers to be severe cupola operation today.

1. The refractory lining in cupolas should be of considerable interest to every foundry operator, because a good lining will mean longer service, more efficient cupola operation and lower maintenance costs. Cupola refractories have been made for a great many years but only recently has the subject of cupola linings been given serious consideration by refractory engineers.

2. For the past fifty years and more, foundrymen have accepted one design of cupola, one type, or kind, of lining while constant study has been made of melting cast iron. The engineering world has paid little if any attention to the main machinery or utensil for doing this. Our grandmothers and great grandmothers had iron and copper kettles and they knew they could not make preserves in the iron kettle. Moreover, they knew the iron was heavy and clumsy and they demanded lighter and better designed kettles—and got them. But the foundryman has been cooking in the same style pot for generations and generations—cooking all sorts of messes, in one design of cupola. Do you not think it is time we thought of a few of these things?

3. Probably the most important item of study in this problem is the question of refractories, especially under severe operating conditions. Of course, what was considered severe operating conditions a few years ago is smiled at today. There is no reason

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Note: This paper was presented at a session on Refractories at the 1936 A.F.A. Convention, Detroit, Mich.

that what we consider severe operating conditions today should not be considered commonplace conditions a few years hence. There are a great many different ideas as to what constitute severe cupola operating conditions. Each plant executive thinks he has the severest condition, such as long continuous service, 6 to 8 hours to get cupolas back into operation necessitating the use of water for cooling, cupola run over-capacity, dirty returns, high

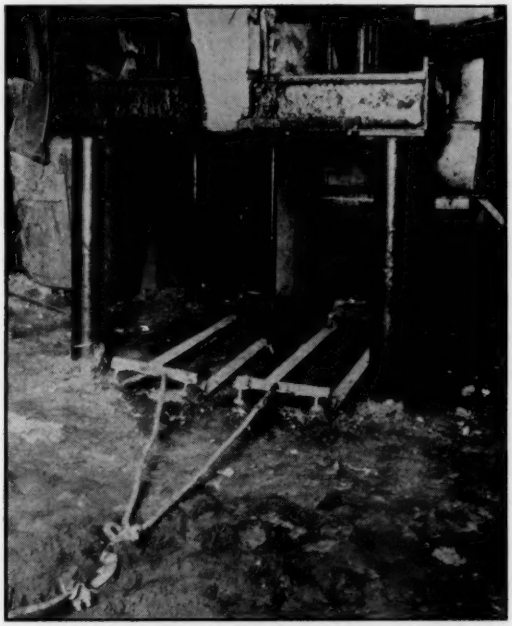

FIG. 1—TYPE OF SKID USED TO REMOVE THE DROP FROM BENEATH CUPOLAS.

per cent steel, high per cent scrap iron, bulky material, fine material, intermittent cupola operation, etc.

4. Perhaps the ideal might be this: Light a cupola Monday morning, drop bottom Friday night, back into operation again the following Monday. This need not necessarily be a continuous operation, but operate 8 to 16 hours per day, melt out and bank, start all over again the next day. To gain this Utopia in cupola operation, it must come about in a cooperative manner. The cupola liner, cupola operator, metallurgist, chemist, ceramic engineer, refractory engineer, refractory manufacturer, coke manu-

facturer, the mechanical engineer, combustion engineer, cupola manufacturer, fan equipment manufacturers, foundry owners and managers—all will have to collaborate to make a thorough study of cupola design, cupola wall thickness, heat transfer, blast (temperature, moisture content and pressure), coke, tuyere design, refractories, slags, composition of metal and method of charging, thereby getting cupola variable factors under control.

5. The writer will set up several cases which he considers to be *"severe operating conditions"* and will give his observations as to the behavior of the cupola refractories under these conditions.

6. The conditions set up are six in number and are designated as Cases 1, 2, 3, 4, 5 and 6. These cases involve various periods of operation and different methods of lining, cooling, lighting up, draft in several sized cupolas. In all these cases, the tuyere area ratio has been kept constant (1 to 4) and the iron melted fairly so, only three different mixtures being used.

7. Fig. 1 shows the type of skid used to remove the drop from beneath the cupolas cited in this paper.

CASE 1

8. Fig. 2 shows a cupola shell of 64-in. diameter lined down to 45-in. diameter and boshed at the melting zone so that the minimum diameter is 36-in. Total height of the boshed portion is approximately 50-in. Fig. 2 also shows the method of lining. The furnace is designed to melt 2 to 7 tons of metal per hour. Height of tuyeres, slag and tap holes are shown. Two mixtures are melted in this furnace, Mixture 1 to give an iron containing 3.50 per cent total carbon and 2.00 per cent silicon and Mixture 2 to give an iron with 3.25 per cent total carbon and 2.25 per cent silicon.

Example 1

9. Referring to Fig. 2, the dotted line Ex. 1 shows the extent to which the lining in the melting zone is burned out after 17 hours of operation. The first tap was made at 6:00 A. M., and the bottom dropped at 11:00 P. M. It required 7 hours to drop the bottom, remove the drop with skids, cool the lining with water, patch-line the melting zone, make the bottom, burn in the coke bed (use wood) with forced draft and melt down and tap again at 6:00 A. M.

10. With such a practice, using cold blast, the melting zone

burns out 6 to 8 in. deep and 35 to 40 in. high and it is necessary to reblock the melting zone and well each week of 5 or 6 days' operation.

Example 2

11. With the same furnace operated 9¼ hours with the first tap at 5:45 A. M. and bottom dropped at 3:00 P. M., 14¾

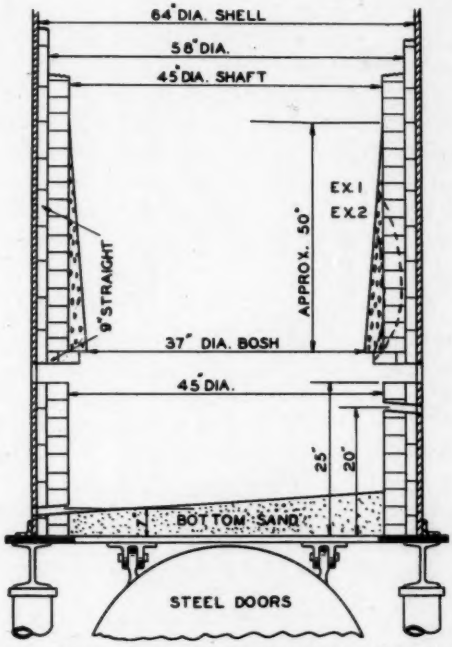

FIG. 2—METHOD OF LINING CUPOLA FOR OPERATION AS IN CASE 1. DOTTED LINES SHOW HOW LINING BURNS OUT.

hours remain for cupola repair, making bottom, burning coke bed, etc., before the first heat is tapped at 5:45 A. M. next morning.

12. Under these conditions, the furnace, instead of being cooled with water immediately after removal of the dump, is cooled with a natural draft for 3 to 4 hours, followed with a minimum amount of water to further cool the lining so that the necessary patching can be done, and the coke bed burned by natural draft, using wood for lighting. The same cupola operating under these conditions will burn out in the melting zone as shown by dotted line Ex. 2, Fig. 2, 4 to 5-in. deep and 30 to 36-in. high

and the melting zone and well will give service of from 6 to 8 weeks.

CASE 2

13. Fig. 3 shows a shell 90-in. in diameter, lined in the same manner as the cupola in Fig. 2 to 72-in. diameter and boshed to 60 in. The heights of the boshed area, slag and tap holes and

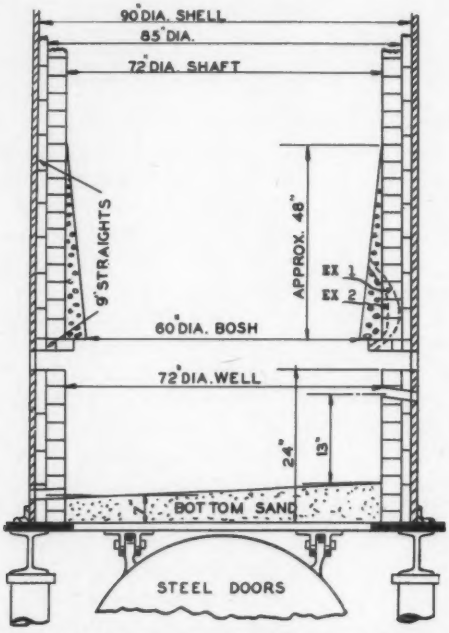

FIG. 3—METHOD OF LINING CUPOLA FOR OPERATION AS IN CASE 2. DOTTED LINES SHOW HOW LINING BURNS OUT.

tuyeres are shown. The furnace is designed to melt from 3 to 23 tons per hour. Three types of iron are melted in this cupola, one containing 3.50 per cent total carbon, 2.00 per cent silicon; the second, 3.25 per cent total carbon and 2.25 per cent silicon; and the third, 3.00 per cent total carbon and 1.80 per cent silicon.

Example 1

14. If this cupola is operated for 19 hours with either hot or cold blast, from 7:00 A. M., the time of the first tap, to 2:00 A. M., the time the bottom is dropped, 7½ hours remain to re-

move drop with skids, cool with water, patch-line melting zone, burn coke bed with forced draft, etc., before the first heat is tapped at 9:30 A. M. the next day. Under these operating conditions, the melting zone burns out 6 to 9-in. deep and 18 to 30-in. high, as shown by the dotted line Ex. 1, Fig. 3, and it is necessary to reblock the melting zone and well each week of 5 to 6 days.

Example 2

15. With the same cupola operated 11 hours, *i.e.*, tapped at 7:00 A. M., bottom dropped at 6:00 P. M. and tapped at 7:00 A. M. the next morning, and under the same condition of cooling as in Case 1, Example 2, but using forced draft instead of natural draft to burn the coke bed, the melting zone is burned out as is shown by dotted line Ex. 2, Fig. 3, 5 to 6 in. deep and 18 to 24 in. high. Under these conditions, the melting zone and well will give service for 6 to 8 weeks of 5 or 6 days each.

CASE 3

16. Fig. 4 shows a 78-in. diameter shell lined down to 52-in. and boshed to a minimum of 42-in. just above the tuyeres. The cupola in Fig. 4 is lined differently than those of Figs. 2 and 3. In this case, two courses of brick laid flat are used. This cupola uses cold blast, has the same tuyere area ratio as those of Figs. 2 and 3, melts from 3 to 12 tons per hour. Heights of boshed area, tuyeres, slag and tap holes area shown. Two mixtures are used, one producing an iron containing 3.50 per cent total carbon and 2.00 per cent silicon and the other 3.25 per cent total carbon and 2.25 per cent silicon.

Example 1

17. If this cupola is operated in such a manner that the time elapsed from the tapping of the first heat at 7:00 A. M. until the bottom is dropped (12 Midnight) is 17 hours, 7 hours remain to repair the lining and be ready to tap the first heat at 7:00 A. M. the next morning. In this case the melting zone is cooled with water and the bed burned with forced draft, other operations being the same as in previous cases. Under these conditions, of operation and melting, two mixtures, one of which produces iron having 3.50 per cent total carbon and 2.00 per cent silicon, the other 3.25 per cent total carbon and 2.25 per cent silicon, are used and the melting zone will burn out 6 to 10-in. deep and 18 to 26-in.

high, as shown by dotted line Ex. 1, Fig. 4. It will be necessary to block the melting zone and well each 5 or 6-day week.

Example 2

18. If the same cupola is operated to tap the first heat at 7:00 A. M. and the bottom dropped at 5:00 P. M. (10 hours), 14

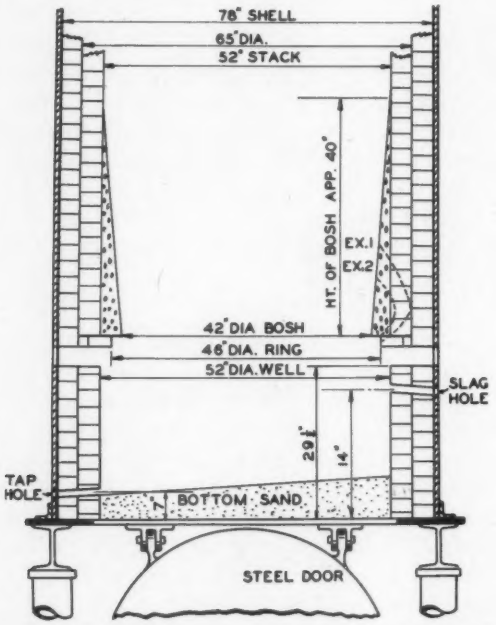

FIG. 4—METHOD OF LINING CUPOLA FOR OPERATION AS IN CASE 3. DOTTED LINES SHOW HOW LINING BURNS OUT.

hours remain for repair, and other operations incidental to tapping the first heat at 7:00 A. M. the next morning. Under these conditions, when the furnace is cooled under the same conditions as in Case 1, Example 2, the melting zone burns out 4 to 6-in. deep and 16 to 24-in. high, as shown by dotted line Ex. 2, Fig. 4, and will, together with the well, give service for 5 to 7 weeks.

CASE 4

19. Fig. 5 shows a cupola shell 100-in. in diameter lined down to 68-in. by the method shown in the illustration, and boshed

to a minimum of 60-in. diameter just above the well. This cupola has a melting capacity of 10 to 24 tons per hour and is used to melt a mixture which produces an iron containing 3.25 per cent total carbon and 2.25 per cent silicon, using hot blast. The tuyere area ratio is the same as in the preceding cases and the heights of the tuyeres, boshed area, slag and tap holes are as shown in Fig. 5.

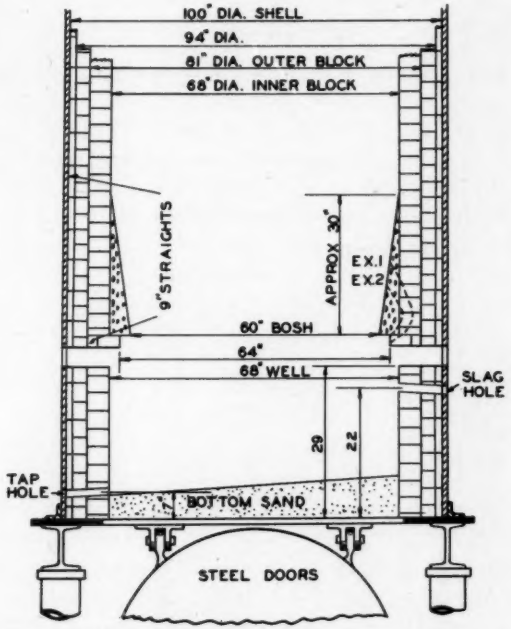

FIG. 5—METHOD OF LINING CUPOLA FOR OPERATION AS IN CASE 4. DOTTED LINES SHOW HOW LINING BURNS OUT.

Example 1

20. When this cupola is operated for 16¼ hours, *i.e.*, tap the first heat at 7:15 A. M. and drop the bottom at 11:30 P. M., 7¾ hours remain for repairing the melting zone, cooling, burning the coke bed, charging, etc., so as to be ready to tap at 7:15 A. M. the next morning. Using the same procedure as in Case 1, Example 1, the melting zone is burned out 6 to 8-in. deep and 24-in. high as shown by dotted line Ex. 1, Fig. 5, and it is necessary to reblock the melting zone and well each 5 or 6-day week.

Example 2

21. This same cupola, is operated for 9¾ hours, *i.e.*, dropping the bottom at 5:00 P. M. instead of 11:30 P. M., and cooling under the same procedure as Case 1, Example 1, will burn out in the melting zone 4 to 6-in. deep and 18-in. high, as shown by the dotted line Ex. 2, Fig. 5. Operating under these conditions, the melting zone and well will give service for 5 to 7 weeks.

CASE 5

22. Fig. 6 shows a 90-in. diameter cupola shell lined down to 71-in. diameter in the same manner as those of Figs. 2 and 3. It has a melting capacity of 10 to 24 tons per hour with a mixture that gives an iron containing 3.25 per cent total carbon and 2.25 per cent silicon using hot blast. Tuyere area ratio is the same as in the previous cases and the boshed area, tuyere, slag and tap-hole heights are as shown.

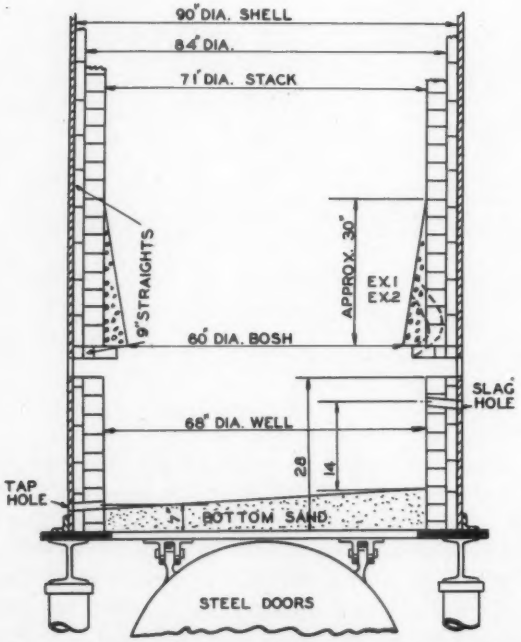

FIG. 6—METHOD OF LINING CUPOLA FOR OPERATION AS IN CASE 5. DOTTED LINES SHOW HOW LINING BURNS OUT.

Example 1

23. Operated on a 16¼ hour schedule, *i.e.*, the first tap at 7:15 A. M. and bottom dropped at 11:30 A. M., 7¾ hours remain to patch-line the melting zone and other operations incidental to tapping the first heat at 7:15 A. M. the next morning, using the same procedure as in Case 1, Example 1.

24. Under these conditions, the melting zone will burn out 6 to 8-in. deep and 24-in. high, as shown by the dotted line Ex. 1, Fig. 6, and it will be necessary to reblock the melting zone and the well each week of 5 or 6 days.

Example 2

25. The same cupola operating for 8¾ hours, *i.e.*, dropping the bottom at 5:00 P. M. instead of 11:30 P. M., allows 14¼ hours for repair of the melting zone, etc., until the first heat is tapped at 7:15 A. M. the next morning, using the same procedure as in Case 1, Example 2. Under these conditions the melting zone will burn out, as shown by the dotted line Ex. 2, Fig. 6, 4 to 6 in. deep and 18-in. high but it will be necessary to reblock the melting zone and well only every 5 to 7 weeks.

CASE 6

26. Fig. 7 shows a 78-in. diameter cupola shell lined down to 58-in. diameter in the same manner as shown in Figs. 2, 3 and 6. The furnace is designed to melt from 3 to 12 tons per hour. Tuyere, boshed area, slag and tap-hole heights are shown. This cupola uses a mixture which gives an iron containing 3.00 per cent total carbon and 1.80 per cent silicon and either hot or cold blast.

Example 1

27. If this cupola is operated for 18½ hours with the first heat tapped at 4:30 A. M. and the bottom dropped at 11:00 P. M., 8 hours remain for cooling the melting zone, etc., under the procedure as in Case 1, Example 1, to tap the first heat at 7:00 A. M. the next morning. Under these conditions the melting zone burns out, as shown by the dotted line Ex. 1, Fig. 7, 8 to 10-in. deep and 24 to 36-in. high, but the slag-hole area, Ex. 1, burns out to the 9-in. straights and quite often to the shell. Operating under these conditions, it is necessary to reblock the melting zone and well each 5 or 6-day week.

Example 2

28. Tht same cupola operated for 9 hours, *i. e.*, the first heat tapped at 7:00 A. M. and bottom dropped at 4:00 P. M., allows 15 hours to repair the melting zone, etc., under the same procedure as in Case 1, Example 2, only allowing 4 to 5 hours for air cooling, so as to tap the first heat at 7:00 A. M. the next

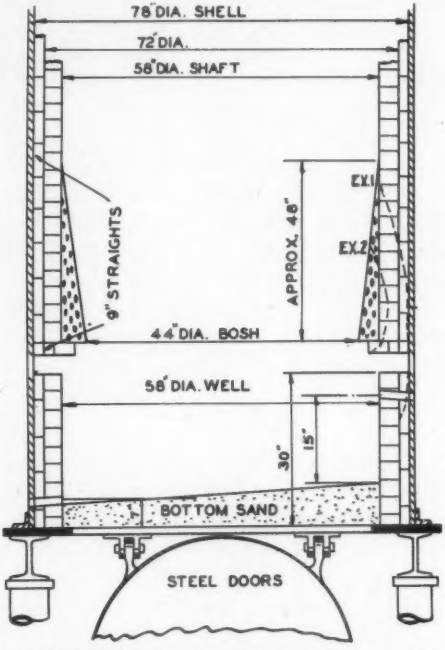

FIG. 7—METHOD OF LINING CUPOLA FOR OPERATION AS IN CASE 6. DOTTED LINES SHOW HOW LINING BURNS OUT.

morning. Under these operating conditions, the melting zone burns out 6 to 8-in. deep and 20 to 36-in. high, as shown by the dotted line Ex. 2, Fig. 7, and the melting zone and well will give 2 to 3 weeks service.

CONCLUSIONS

29. From our observations of the results given in the illustrations, the following conclusions may be drawn:

(1) Length of heat determines how badly a cupola will burn rather than the tonnage per hour.

(2) Water should not be put on the cupola lining.

(3) Cupola allowed to cool by natural draft will materially increase the life of the refractory.

(4) New lining should be thoroughly dried before being put into operation.

(5) Cupola should be brought up to heat slowly.

(*Discussion Begins on Page 281.*)

Overcoming Spout Trouble By Use of a Monolithic Trough Tile

By J. A. Bowers* and Charles Green,** Birmingham, Ala.

Abstract

This paper describes how certain difficulties encountered in a peculiar arrangement of a hot metal trough were overcome by the use of a specially designed trough tile. Tests were made on the refractory material until a composition giving the desired properties was secured. A comparison of costs entailed by the old and new methods shows a decided saving in material and labor by the use of the special tile.

1. New shop practices in the cast iron pipe industry have called for and are being met with more specialized refractories, both in composition and design. Higher cupola operating temperatures, greater capacities, and longer continuous runs have placed an added responsibility and overload on the refractories comprising the lining of the furnace and the hot metal trough connecting the cupola battery with the forehearth.

2. The discussion in this paper will be confined to a problem dealing with the connecting trough. This discussion comes under two headings; namely, (1) a description of the cupola battery serviced by the forehearth, and enumeration of the service conditions to be met; (2) development of a refractory tile design and composition which fulfilled these service requirements.

The Problem

3. In January, 1935, the American Cast Iron Pipe Company put in a 12-ton forehearth for service in the mono-cast shops. The construction was somewhat peculiar due to the particular arrange-

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** Ceramic Engineer, Alabama Clay Products Co.

Note: This paper was presented at a session on Refractories at the 1936 A.F.A. Convention in Detroit, Mich.

ment and equipment used in the shop for carrying iron from the cupola.

Tilting of Ladle

4. First among these peculiarities was the fact that the forehearth ladle could not be tilted from the center as most ladles are. The arc of the lip had to be held to a minimum because the individual bull ladle, once spotted, could neither be moved forward nor backward; for this reason our forehearth ladle is tilted about the

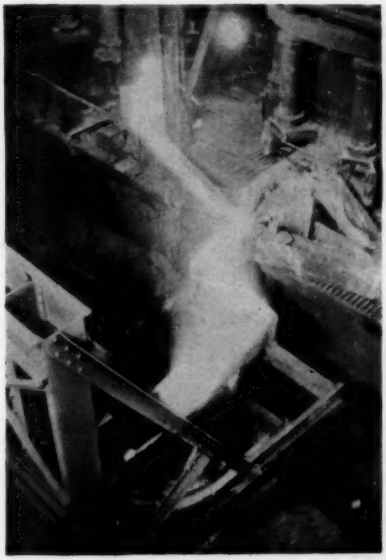


Fig. 1—Showing Flow of Metal from Cupola to Forehearth.

lip, that is the trunions are centered in a line with the lip of the ladle.

Length Iron Travels in Spout

5. Another peculiarity of this installation is that because of the construction of the monorail crane, iron from the cupola must be turned 90 degrees for a distance of approximately 4 ft. and then turned 90 degrees again for approximately 3 ft. to flow into the forehearth. This makes it necessary to have about 18 ft. of iron trough from one cupola and 23 ft. for the other two. (Fig. 1.)

Holding Iron in the Trough.

6. Because of distance traveled and the turns made, considerable trouble was encountered in holding the iron. This difficulty was overcome by breaking or splicing all joints, as shown in Fig. 2. This method called for considerable care and skill in laying the brick; they were jammed as close together as possible, using a

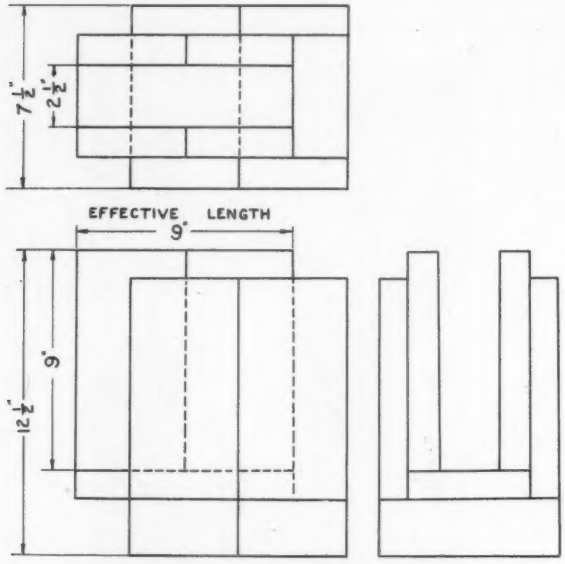


FIG. 2—METHOD OF LAYING TROUGH BRICK.

soupy mixture of fire clay and finely ground fire brick as a mortar. With this care and constant inspection, all run-outs and leaks were prevented. However, this method called for continued brick replacement, especially the side wall splits, that due to expansion and contraction, mechanical wear, and other causes, were continually falling in or working loose.

7. Another fault of this method was the amount of labor necessary to repair the entire trough when needed. As can be seen from Fig. 1, two 9-in. straights and nine 1.25-in. splits were required to complete 9 in. of the trough.

8. Since 28 ft. of trough had to be lined in this manner, it

may be easily seen that labor was quite a problem. In other words, the following service conditions had to be met:

(1) Chemical reaction and erosion.
(2) A definite thermal and mechanical spalling condition.
(3) Mechanically correct design to eliminate run-outs and primary failure of brick joints, necessitating replacements.
(4) Accuracy of shape to insure regular, uniform flow uninterrupted by "bridge-overs" caused by irregularities in inside trough dimensions.
(5) Cut labor necessary to properly build the trough.

Obtaining Suitable Composition of Refractory.

9. In arriving at the composition best suited to the first two service conditions enumerated above, the refractory bodies of the composition, given in Table 1, were made up and life tests determined by actual shop service.

Table 1

Analysis of Test Refractories

	A	B	C
SiO_2, Per Cent	65.90	62.00	60.60
Al_2O_3, Per Cent	29.80	31.06	34.10
Fe_2O_3, Per Cent	3.30	2.01	1.70
TiO_2, Per Cent		1.49	1.50
CaO and MgO, Per Cent	0.57	0.98	0.60
Alkalies, Per Cent	0.33	1.95	1.40
Fusion Point—Pyrometric Cone	28	31	32.5
Equivalent °F.	2939	3056	3100
Per Cent Porosity (Approximate)	8.2	18.0	22.2
Per Cent Absorption	3.8	8.6	10.8

10. Composition *A* proved satisfactory as regards chemical resistance and resistance to erosion, but lacked proper resistance to spalling. *B* showed excellent resistance to chemical and erosive attack, and was also highly resistant to spalling. This composition was adapted as standard. *C* was satisfactory as regarding spalling, but was not on a par with the first two in resistance to chemical attack and erosion.

11. In meeting service conditions Nos. 3, 4 and 5, the trough shaped design of tile now in use, each of which is equivalent to laying eleven brick, shown in detail in Figs. 3 and 4, were found

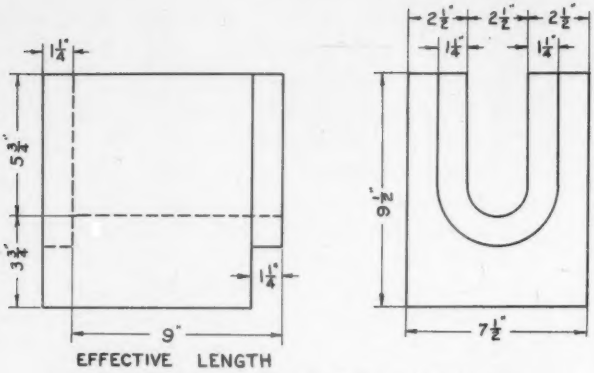


FIG. 3—DESIGN OF NEW TYPE TROUGH TILE NOW USED.

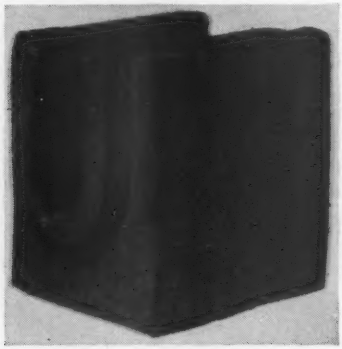


FIG. 4—ILLUSTRATION OF ONE OF THE NEW TROUGH TILE.

to solve these problems. As shown, joints are reduced to a minimum, and these are protected by ship-lapping joints, giving a 1.25-in. lap joint. In other words, the iron must travel 3.75 in. through a tight fitting joint which has been grouted with a special composition of finely pulverized, non-plastic, and dense fire clay to form practically, and literally a monolithic trough. The accuracy of size of each monolithic segment is carried to a high degree by careful control of the mix, the grinding, moisture content of the plastic mass, and controlled drying and firing. In laying these tile the male end is dipped in the soupy mixture mentioned above and after engaging this end in the preceding female end the tile is rapped tightly into place.

12. Compared to the 3.5 man-days required in the old method, one man-day is all that is required to line the troughs completely with this tile. Furthermore, these tile last for at least twenty 9-hour heats, that is they carry at least 4500 tons of molten iron without any replacements, and then replacements are made as needed without any extra labor. The only work required during the first 16 heats is the removal of small amounts of slag clinging to the side walls and washing them with blacking.

13. The design and service of this monolithic tile*, used in the shops of the American Cast Iron Pipe Company, have proved very successful, for the following reasons:

(1) Run-outs are unknown.
(2) Bridge-overs or "freeze-ups" in the hot metal trough are eliminated.
(3) The life of the trough has been increased considerably.
(4) The cost of the necessary labor has been cut almost in half.
(5) Due to the accurate workmanship on these tiles the misfits are negligible; in fact there have been none.
(6) The design of this type trough tile can be successfully applied to any type hot metal trough known.

14. Data on our costs, which bear out the above statements, are shown in Table 2.

Table 2

Comparison of Costs of Old and New Methods

	Tile Method	Old Method
Refractory Cost to Reline Entire Trough	$ 8.10	$10.17
Refractory Cost for Upkeep Before Relining	3.00	8.00
Number of Heats Completed Before Relining	20	14
Cost of Labor Necessary to Reline Entire Trough	6.00	13.50
Cost of Labor Necessary for Upkeep Before Relining	Approximately the Same Under Both Methods.	

* Patent pending.

(*Discussion Begins on Page 281.*)

Notes on Some Foundry Refractories

By John D. Sullivan,* Columbus, O.

Abstract

The refractory requirements and life of the most important iron and steel and foundry furnaces are discussed. The effect of refractory developments of the past decade on refractory life and furnace performance are considered. Among the important new developments are: Low-iron magnesite brick, chemically-bonded unburned magnesite and chrome, forsterite, volume-stable high-alumina, high-fired and chemically balanced chrome, and super duty fireclay bricks. Insulation has not only affected fuel savings but in most cases improved refractory life. Light-weight brick of low thermal capacity are advantageously employed in intermittently operated heating furnaces. Extended use of power-pressing, careful grading of particle size, and de-airing methods have resulted in brick of better texture, higher density, and freedom from imperfections.

1. The purpose of this paper is to summarize some of the refractory problems and requirements in the foundry and iron and steel industries. Although the widest use of the basic open-hearth is not as a foundry furnace, it is used as such to a limited extent. Moreover, the foundry industry depends on basic steel scrap as part of its charge. The problems of the basic open-hearth are in many respects similar to those of the acid open-hearth used for making steel castings. Moreover, the many interesting refractory problems and the advances along this line make it appear worth while to include such furnaces in this discussion. Another aim is to discuss refractory developments of the past decade and the effect on furnace performance and life. Some of the information presented is already available in the technical literature but much of it is from obscure publications, private communications, and personal observations. It is hoped that a condensed summary

* Chief Chemist, Battelle Memorial Institute.

of this nature will be of value to foundry operators and metallurgists, and to students.

2. The ceramic industry depends on the metallurgical industries as the chief outlet for refractories. Paul M. Tyler[1] estimates the current distribution of refractory sales in dollars to be as given in Table 1.

Table 1

ESTIMATION OF CURRENT DISTRIBUTION OF REFRACTORY SALES

(*P. M. Tyler*)

Industry	Per Cent of Total Sales
Iron and Steel	50
Public Utilities	20
Non-Ferrous Metals	6
Cement and Lime	5
Glass	5
Oil Refining	4
Ceramic Miscellaneous	3
Miscellaneous	7

3. A study[2] made in 1923 indicated that open-hearth furnaces took over 1/3 of the refractory brick, blast furnaces and heating furnaces about 7 per cent each, cupola and smelting furnaces between 3 and 4 per cent each, and malleable iron plants over 2 per cent.

BASIC-OPEN HEARTH FURNACES

4. Basic open-hearth furnaces are the greatest users of refractories and they present a variety of refractory problems with rigid requirements. Buell[3] states that there are less than 1000 basic open-hearth furnaces in the United States, classified as given in Table 2. Typical basic open-hearth slags analyze as given in Table 3.

Bottoms

5. Open-hearth bottoms usually consist of metal plates lined with fireclay brick, followed by basic or neutral brick, and finally on top a fused layer of dead-burned magnesite mixed with 10 to 25 per cent of open-hearth slag. Up to about 10 years ago, magnesite brick were used almost exclusively for furnace bottoms but

[1] Private Communication.

[2] *"Where Refractory Bricks Go,"* IRON AGE, *112*, 1923, p. 402.

[3] Buell, Wm. C., *"Minutes of 17th Open-Hearth Conference at Pittsburgh, Pa.,"* 1934, p. 20.

today, because of cost, they have been largely replaced by chrome brick. Statistics are no longer published on chrome and magnesite brick production, but estimates vary from 2 to 10 chrome to 1 magnesite brick. However, it is still general practice to use magnesite brick around tap holes, and a few companies still use all-magnesite bottoms. In some plants, crushed chrome covers the brick, and a thinner layer of grain magnesite is employed in the hearth.

6. In recent years, most new furnaces employ insulation between the metal shell and fireclay brick. A typical open-hearth bottom of today may have 2½ to 4 in. of insulation, 4½ to 13 in. of fireclay brick, 6 to 12 in. of magnesite or chrome brick, and 12 in. of sintered magnesite plus slag mixture.

7. Open-hearth bottoms last about 20 years but must be patched after each heat. Deep holes are ordinarily repaired with dead-burned magnesite or prepared refractory dolomite while shallow holes are repaired with raw or calcined dolomite.

8. Various attempts to use cheaper substitutes for bottoms have met with poor success. The hearth must withstand shock during charging, be dense enough to prevent soaking up of the

Table 2

CLASSIFICATION OF BASIC OPEN-HEARTH FURNACES IN THE U. S.

(*Buell*)

Tons capacity	Number
Up to 49	103
50 to 79	276
80 to 109	383
110 to 149	82
150 to 199	59
200 or more	11
Tilting	32

Table 3

ANALYSES OF TYPICAL BASIC OPEN-HEARTH SLAGS

Ingredient	Per Cent
CaO	40-42
MgO	10-8
FeO	15-35
MnO	6-3
Al_2O_3	4-1
P_2O_5	5-1
SiO_2	20-10

slag, resistant to attack by the slag, and thoroughly sintered to avoid holes by virtue of part of the bottom material coming loose.

Roofs

9. The temperature inside the open-hearth furnace is 2800-3000° F. Refractories in the roof must be able to withstand not only this high temperature but also the chemical attack of fumes and corrosive gases laden with solid particles, and sudden temperature changes. Since the furnaces employ sprung arches, the refractories must stand considerable pressure without softening, crushing, or distorting. Iron oxide rising from the bath gradually attacks the silica roof brick and finally causes dripping. Various kinds of brick have been tried in roofs but none are so satisfactory as silica.

10. The life of a roof is variable and depends on the size of the furnace and operating conditions. A few years ago, roofs were replaced every 100 to 125 days which corresponded to 250 to 350 heats for large furnaces and 300 to 400 heats for small ones. During the past few years, roofs have been insulated, and this has resulted in longer refractory life. Insulation has reduced heat loss through the roof so equivalent heat transfer to the bath can be maintained with less fuel consumption or with lower flame temperatures. A more uniform transformation of quartz to crystobalite and tridymite with a resultant brick more resistant to spalling action by temperature changes may also be credited to insulation. Also, the maintenance of a more uniform temperature throughout the entire brick tends to decrease the tendency to spall. Mechanical control of combustion by automatic draft control and flame reversals and maintenance of a balanced draft over the hearth also effected longer life.

11. One operator reported that, prior to insulation, patching of the roof commenced at 275 to 300 heats, at which time patching was required 1 to 4 feet out from the skewbacks, and 425 heats represented a furnace campaign. After insulation, very little patching was done up to 350 heats and the furnace campaign was increased to 470 heats. At another plant the average life of the roof of a 120-ton furnace before insulation was about 350 heats. After insulation, as high as 566 heats were obtained on one campaign. Furnace operators generally report an increase of 10 to 25 per cent in roof life after insulation.

12. Power-pressed silica brick are also being introduced into

roofs. The life appears to be about the same as that from those made by older methods. The general consensus of opinion seems to be that the increased life of a suspended silica roof is not great enough to justify the added cost.

Front and Back Walls

13. Silica front and back walls in general have shorter lives than roofs. Deterioration is caused by absorption of iron oxide from the gas stream, the cutting action of the flame, and spalling. The latter is especially bad in front walls, particularly in door jambs. Chemical attack from slag splashed from the bath and from roof drippings is also bad. Application of fettling is easier with sloping walls, and increased life resulted in plants changing to this design.

14. Front walls generally are constructed of silica brick, usually 13 in. thick, often with a facing of ground chrome ore. Some furnaces use chrome and Kromag brick, unburned chrome, Metalkase magnesite, and a few use unburned magnesite. In some cases, the bottom 4 or 5 courses are magnesite and the rest silica. Patching usually is done with silica. Average life with silica bricks is 100 to 150 heats. Basic and neutral bricks give at least twice the life of silica.

15. Back walls were formerly built almost exclusively with silica brick, usually with one course of chrome brick between them and the magnesite hearth. At the present time burned chrome and Kromag brick are finding extensive use although Metalkase brick and unburned magnesite and unburned chrome brick are also rapidly gaining favor. Today, back walls of basic or neutral brick ordinarily last the life of a furnace campaign. Patching is usually done with ground chrome or chrome cement.

Ports and Bulkheads

16. Abrasion is an important factor due to the changing direction of the gas stream which, ladened with oxide particles, has a more severe cutting action than on the roof. Formerly, silica brick were used almost exclusively, frequently with a coating of fine chrome ore to give a surface more resistance to attack of oxides in the furnace gases. Design of ports probably is equally as important as refractories in determining life of ports and bulkheads. With improved port design, not only longer end but also front-wall life has resulted. One operator reported 40 heats for

an end wall with stationary and 200 with movable ports. Mechanical control of combustion has also increased port life. Silica brick, 12 to 18 in., give as low as 40 and rarely over 125 heats. Chrome brick are finding extensive use and life is 125 to 300 heats, but do not last the life of a furnace campaign. Metalkase and chemically bonded unburned magnesite brick are quite widely used and bulkhead lives of 450 to 500 heats are common. As high as 650 to 700 heats have been reported with 18-in. bulkheads of Metalkase brick. Unburned or chemically bonded chrome brick are also finding extensive use.

17. High-alumina (70 per cent) firebrick have made some excellent records in ports. With these brick, water-cooling is usually employed. With basic or neutral refractories, ports are not water cooled.

18. Forsterite brick are one of the developments of the past 2 or 3 years and they are finding their widest use in bulkheads. Experience has shown that their life is generally of the same order as chemical bonded or Metalkase magnesite bricks.

Checker Chambers

19. Requirements of checker brick are high thermal capacity, high thermal conductivity, resistance to slagging action of dust, and resistance to spalling by temperature changes. Maximum top checker temperatures vary widely in different furnaces but in general are from 2300 to 2600° F. Silica brick have been used widely in the past but now fireclay brick are ordinarily used. Within the past 2 or 3 years, the tendency has been to use super fireclay brick (Cone 33) at least for upper courses. These brick are denser, more refractory, and have less tendency to spall than high-duty fireclay or high-alumina bricks. The dust that accumulates in checkers is ordinarily Fe_3O_4. In air checkers, this usually does not flux the brick and gradually accumulates until it has to be removed. In gas checkers, the Fe_3O_4 is reduced to FeO which reacts with the refractories. The super fireclay refractories apparently are not so readily clogged and are more easily cleaned than ordinary fireclay brick. Their density gives them better thermal capacity and conductivity.

20. The usual life of top course checkers is 150 to 300 heats, although one operator reported 738 heats on a 2-pass checker with the first one not burned out at that time. Usually in repairing

checkers, only the upper ½ to ⅓ is removed, and up to 70 per cent of the removed brick are recovered.

21. Magnesite and chrome brick have been tried but the results have not been satisfactory. Silica brick have been found inferior to high-grade fireclay.

22. Insulation to prevent air infiltration and to conserve heat has resulted in increased efficiencies, and mechanical control of combustion has increased checker life.

Ladles for Steel

23. Ladle linings must be dense enough to resist penetration and should be inert to silicates high in lime and iron oxide. The refractory should be resistant to the cutting action of a stream of steel at 2800° F., and yet not spall. It must not adhere to the skull of metal and be pulled out when the latter is removed. Tight joints are essential and allowance must be made for thermal expansion. Accuracy and uniformity of size are important.

24. Fireclay brick that are rather soft to withstand spalling and not highly refractory are used. Ordinarily, 8 to 10 heats represents a ladle lining life but improved refractories have in some instances increased this to 15 to 20. In rare instances, lives of 30 to 35 heats have been obtained. High-carbon steels are easier on ladle refractories than low-carbon steels. Lining life can be increased by use of a clay slurry but cleanliness of the steels is endangered. Some attempts have been made to use basic linings but the results were not satisfactory. Spalling was bad, the slag tended to stick, and the lining was damaged in removing skulls. Monolithic linings of crushed ganister bonded with clay have given long life in some steel casting plants employing acid furnaces.

25. Insulation has been successfully applied to ladles. Usually this takes the form of a layer 1 to 1½ in. thick between the metal shell and the firebrick lining.

ACID OPEN-HEARTH FURNACES

26. Acid and basic open-hearth furnaces differ essentially only in hearth composition. Bottoms are made of silica brick covered with sintered layers of silica sand. The hearth gradually absorbs iron oxide during melting of the charge and the bottom thus becomes a mass of silica bonded with iron and other silicates which gradually increase in amounts with absorption of more silica until the refractoriness of the bottom is destroyed. The slag,

consisting essentially of iron silicate, attacks the hearth at the slag line. Repairs are made after each heat with crushed ganister or silica sand.

27. Acid open-hearth furnaces are not run at such high performance demands as basic, and the refractory life is considerably longer. The roof life is commonly 1000 to 1500 heats, which constitutes a furnace campaign. At the end of that time the entire furnace is rebuilt above the floor line. Back walls ordinarily last the life of the roof if the practice of banking silica sand clear to the skewbacks is followed. The banking is given a thorough repair at least once a week. Front walls ordinarily last the life of the furnace, except jambs which require replacement once during a campaign. The end walls last a campaign but the end panels on either side of the burner have to be replaced every 200 to 250 heats. Checker brick are generally silica and ordinarily last an entire campaign, at which time the top courses are replaced. Checker brick life is better in acid than in basic furnaces. One

Table 4

TYPICAL BLAST FURNACE SLAG ANALYSIS

Ingredient	Per Cent
SiO_2	33
CaO	48
MgO	5
Al_2O_3	12
FeO	1
Others	1

reason is that basic slag carried in the gases attacks and clogs checkers. Whereas basic bottoms ordinarily last 20 years, acid bottoms are entirely replaced after each campaign or run. About 10 per cent of the bottom bricks are recovered.

28. Insulation is gaining favor in the acid open-hearth industry, and the advantages of fuel savings and better refractory life are reported.

29. In general, the destruction of upper parts of the furnace and clogging of checkers are caused by similar influences discussed under basic open-hearth furnaces, except that, in the latter, basic slag in the gases and by splatter accentuates attack.

THE BESSEMER CONVERTER

30. Only the acid Bessemer process is in use in the United

States. The bottom of the converter is fastened to the body so that it can be detached readily and replaced with a new one. The lining is usually constructed of blocks of silica stone or schist with fireclay between them. Rammed mixes of silica or ganister bonded with fireclay are less frequently used. Minor repairs must be made after nearly every heat and more extensive ones about once a week. Lining life depends to a large extent on the care given to making repairs, and with proper precautions lives of 10,000 to 20,000 heats may be attained.[4] Converter slags are highly silicious and corrode the lining only slightly.

31. Uncombined iron oxide attacks silica rapidly; so attack around the tuyeres is quite rapid. Bottoms last only 25 to 30 heats. They are built by placing fireclay tuyere blocks in position and filling around them with silica containing clay as a bond and usually some coke breeze. A bottom ordinarily has 15 to 30 tuyeres each with 12 to 18 holes of approximately ½-in. diameter. Bottom life is shortened[4] by: (1) hotter blows, (2) longer blows, (3) lower blast pressure, because the blast holds the metal away from the mouth of the tuyeres, and (4) more manganese in the pig iron, because the resultant slag is more corrosive.

IRON BLAST FURNACES

32. A single blast furnace lasts for several years of continuous service but it ranks high as a consumer of refractories because of the large number required in construction. Depending on size, a furnace requires from one-fourth to one million 9-in. equivalent bricks.

33. Lining life varies with the kind of iron made, the character of the charge, and the quality of stock distribution. Lining life is shorter in making ferroalloys than when pig iron is the product. The hearth receives molten metal and slag at a temperature of 2500 to 2800°F., and at the time of tapping holds 100 to 250 tons of molten metal. This weight plus the blast pressure puts a severe load on the refractories, especially at the bottom.

34. The temperature at the tuyere zone is 2900 to 3100°F. but is considerably lower at the surface of the inwall. A typical slag analysis is given in Table 4.

35. Fireclay brick are used in construction of blast furnaces. Bricks containing a high content of flint clay are finding wide application in hearths and boshes. Power pressing and vacuum

[4] Stoughton, B., *"Metallurgy of Iron and Steel,"* McGraw Hill Book Co. Fourth Edition, 1934, pp. 177-178.

methods of fabrication have been introduced to yield denser and more uniform product. The greatest improvement in blast-furnace brick in the past few years is a harder burned brick. Harder burning is employed to unite all of the iron oxide as silicate because free oxides may effect disintegration of the brick through carbon deposition as discussed in detail later in this paper.

36. The principal refractory requirements of hearth and bosh are resistance to deformation under load at high temperatures and resistance to chemical attack by the slag. Brick should be dense to prevent penetration of slag and molten metal and hard enough to prevent abrasion by the charge, especially at the bosh. Water-cooled plates are placed in the wall to maintain the bricks in the hearth and bosh at low enough temperatures to remain rigid at operating temperatures and to resist the attack of the slag.

37. Shaft brick are not so refractory as those in lower parts of the furnace. Cooling plates are used part way, and at the top the temperature is only about 400°F. Brick should be hard to resist abrasion, strong enough to stand the shock of introduction of charge, and the iron should be in the form of silicate because iron oxides (FeO, Fe_3O_4, or Fe_2O_3) and possibly metallic iron catalyze the reduction of carbon monoxide to carbon dioxide and carbon. Carbon deposits build up until the bricks disintegrate.[5] The maximum reaction rate occurs[6] between 450°C. (842°F.) and 500°C. (932°F.). Zinc in the charge has also been known to cause lining failures. Alkali vapors condensing in the upper cooler parts of furnaces sometimes cause decrease in refractory life.

38. Improved refractory manufacture and use of cleaner gases and higher temperatures in stoves have improved blast-furnace practice and lengthened refractory life. Formerly 1,000,000 tons of iron was considered good refractory life for a blast furnace, but today a life of 1,500,000 tons is expected and 2,000,000 has been attained.

IRON CUPOLA

39. The temperature of the metal at the spout averages about 2650°F. and may be as high as 2750°F. The temperature in the

[5] Nesbitt, C. E. and M. L. Bell, *"The Disintegration of Firebrick Linings in Iron Blast Furnace,"* YEARBOOK, Amer. Iron & Steel Inst. 1923, pp. 216-242. O'Harra, B. M. and W. J. Darby, *"The Disintegration of Refractory Brick by Carbon Monoxide,"* JOUR. Amer. Cer. Soc. *6*, 1923, p. 904

[6] Furnas, C. C., *"The Mechanism and Rates of Some Heterogeneous Reactions Applicable to Ceramics,"* paper presented to Refractory Division of Amer. Cer. Soc., Buffalo, N. Y., Feb. 20, 1935.

melting zone may be 2900°F. or even higher. Cupola brick must resist high temperatures, abrasion, and mechanical stresses. The calcium-aluminum-silicate slag, sometimes high in iron oxide, is corrosive. The entire lining of a cupola is replaced only about once a year, but the melting zone usually must be replaced every day. Spalling requirements are quite strenuous. In ordinary practice, only about an hour is taken to heat the cupola before turning on the blast to melt the charge. The destructive practice of cooling the lining at the conclusion of melting by dropping the bottom and spraying with water is also followed.

40. The melting zone is lined either with silica stone or fireclay blocks. Formerly all cupola blocks were hand made, and many are still so produced. They were rather porous, somewhat fragile, not accurate in size and shape, and did not stand the terrific abrasion and slag action in cupolas. Within the past few years, cupola blocks made by the stiff-mud process and using super duty fireclay mixtures have been introduced. Brick so made are extremely hard and dense and afford better resistance to abrasion and slag penetration. Experience has shown that these brick give about three times as long life in the abrasive zone as the older hand-made blocks.

41. In large production foundries the corrosive action is so severe in the melting zone that hand-made blocks often burn out in less than a day. Stiff-mud brick usually give at least a full day's run. High steel charges cut the refractories in the melting zone worse than low ones. In some instances, silica blocks have given better service than fireclay with high steel charges; life as long as two days has been experienced. Water cooling is sometimes employed. In continuous production foundries, if the 6-in. lining in the melting zone is burned out at the end of the day, it is usually economical to replace with new brick. When only part of the lining is burned out, patching is done with straight and split brick and daubing or patching mixtures. Patching mixes must be highly refractory and should consist of silica sand and plastic fireclay or crushed refractory firebrick and plastic fireclay.

42. Owing to cost factors, introduction of special refractories has met with but little success. In England,[7] rammed monolithic linings are being widely adopted.

43. Cupola forehearths are lined with rammed ganister or ladle bricks with suitable insulation, usually between the shell and

[7] Hamilton, W., *"Refractories in the Foundry and Furnace,"* FOUNDRY TRADE JOURNAL, *54*, 1936, p. 101.

lining. The attack of the soda ash used to lower the sulphur content of the iron is the chief cause of lining failures.

FOUNDRY CONVERTER

44. Foundry converters are similar to Bessemer converters but are usually side blown and the capacity is ordinarily 1 to 3 tons with 2 the most common size. At the present time, in the United States, probably not over 0.5 per cent of all steel castings are made in converters. The Steel Founders' Society Directory for 1935 shows 33 converters in 21 foundries. In England, however, the converter is still the most widely used steel foundry melting medium.

45. In the United States, the converter usually is lined with about 9 in. of fireclay brick and then a 9-in. rammed ganister lining. The usual life is 50 to 60 heats at which time the ganister lining must be re-rammed. Causes of refractory failure are similar to those discussed under Bessemer converters, but since side-blowing is employed it is necessary to replace the lining instead of only the bottom. In continuous service, it is necessary, therefore, to provide converters in pairs so that one can be relined while the other is in service. In England, the practice of using entirely rammed linings is widespread. Some foundries there, about once a week, take out sufficient slag, lining, etc. to permit insertion of templates and ramming of 3 to 4 in. of new lining the full length of the vessel. Others patch daily.

MALLEABLE IRON AIR FURNACE

46. Malleable air furnaces are brought to the melting temperature in about 1½ hours, and the heat is finished in 5 to 8 hours. The corrosive slags, a typical analysis of which is given in Table 5, attack bottom and side wall refractories. The metal

Table 5

TYPICAL ANALYSIS OF A MALLEABLE AIR FURNACE CORROSIVE SLAG

Ingredient	Per Cent
Iron as FeO	28.8
Iron as Fe_2O_3	1.2
MnO	4.8
SiO_2	50.4
Al_2O_3	14.8

may be heated from 2700° to 2850°F., and the flame temperature is probably 100°F. higher.

47. Hearth bottoms, until recently, were made almost ex-

clusively by tamping silica sand, and/or fireclay grog, and plastic clay. Such bottoms were gradually corroded by slag, and damaged during charging and skimming. Average bottom life was 12 to 17 heats. During the past 2 years, super duty fireclay brick (Cone 33) have been introduced into furnace bottoms. Life of 3000 to 7000 tons, which on a 50-ton furnace corresponds to 60 to 140 heats, from a 9-in. bottom has been reported. Cleaner metal and less slag are claimed. High alumina refractories are used to a limited extent. Patching is done with silica plus plastic clay.

48. Sidewalls fail largely through corrosion by the slag and solid particles in the gases. Parts near the removable bungs are subject to spalling. Abrasion during charging may be severe. For sidewalls, a very dense and very refractory brick is desirable. Ten years ago, the Joint Committee on Foundry Refractories[8] of the American Foundrymen's Association and the American Ceramic Society recommended medium burning of first-grade fireclay brick. The average life of a sidewall used in a 20-ton furnace used to be 20 to 25 heats. The life has been approximately doubled by use of super duty fireclay brick, which recently have been introduced into sidewalls.

49. Roof brick fail by corrosion of the solid particles contained in the gas stream and by spalling, especially the removable bungs. Improper setting of clamps may cause failure. In using first-grade fireclay brick, the average life is 15 to 20 ton furnaces as reported by the above-mentioned Joint Committee was 23 heats for charging bungs and 45 heats for firebox bungs with hand coal firing, and 14 heats for charging bungs and 22 for firebox bungs with pulverized coal firing. However, the recently introduced Cone 33 super duty fireclay brick have in many cases doubled bung life over that obtained from high duty fireclay brick. Design changes in bung bricks are also said to have had a beneficial effect on life.

50. The malleable air furnace is an excellent example of improved performance and life that have resulted from introduction of a new type of refractory firebrick. The older "soft" bricks are rapidly being displaced by those of increased refractories and density.

ROTARY FURNACES

51. Rotary furnaces are used primarily for melting gray or

[8] *"Preliminary Report of the Sub-Committee on the Survey of Conditions in the Malleable Industry,"* TRANS. Am. Foundrymen's Assoc., *34*, 1926, pp. 88-117.

malleable iron, although a few attempts have been made to melt steel. The furnace is made to rotate and thus to wash the roof portion with the melt to take up the stored heat. The usual rate of rotation is about 1 r.p.m. Among the furnaces fired by powdered coal are the Brackelsberg, Stein-Brackelsberg, and Sesci. The Buess uses gas, oil, or pulverized coal; the Mezger, gasified fuel oil; the Fulmina, Deblanchal, and Fofumi use oil. Only the Brackelsberg appears to have been introduced into service in the United States; so most of the following discussion relates to that furnace. In England and Europe, there appears to be increased interest in oil-fired rotaries.

52. The present Brackelsberg furnace is a long cylinder with conical ends. Advertising pamphlets show dimensions for various capacities as given in Table 6.

Table 6

DATA ON CAPACITIES AND SIZES OF BRACKELSBERG FURNACES

Capacity, tons	Length of furnace chamber, ft.	Approx. inside diameter of chamber, ft.
2-3	15	about 3
5-6	20	3-4
8-9	24	4-4.8
10-12	25	about 5

53. The pulverized coal burner is at one end but not connected to the furnace. In England,[9] the conical ends of the furnace are now being made the same shape, so that by turning the barrel end for end the effect of local thinning of the lining at one end is obviated and the life of the whole lining appreciably lengthened. Most foreign furnaces are rammed with a silicious lining. About 5 days' time is required to ram a lining, and furnaces employing such linings are mounted on trunnions so that they can be swung to a full vertical position for lining. The American practice is to use brick instead of rammed linings. An outer course of cupola blocks is inserted and inside of this, a lining of silica bricks provided with suitable expansion joints. Refractory demands in Brackelsberg furnaces are severe. The powdered coal flame which shoots onto the refractory walls deposits coal ash and this with iron oxide from the charge rapidly attack the lining. The rotating action also washes the metal and slag over the refractory lining causing erosion as well as chemical attack. Only

[9] THE ENGINEER, *161*, Feb. 28, 1936, p. 241.

acid linings have given satisfaction to date. A magnesite lining was tried in a European furnace but it failed rapidly owing to attack by the coal ash. One of the disadvantages of silica linings is the necessity of running with a low flame while the furnace is idle to keep the temperature above the silica inversion point.

54. The temperature is about 2650 to 2725°F. for gray iron and 2850 to 2950°F. for alloy malleable. On ordinary gray iron, lining lives of 150 to 200 heats are secured, but for malleable iron the average life appears to be about 50 heats.

55. With gas-fired rotaries on malleable with a temperature of 2850 to 2900°F., the life of a rammed lining is usually 75 to 90 heats. In England, reports[10] indicate about 60 heats on steel and 250 on high-test cast iron in a gas-fired furnace. With oil-fired furnaces in England, the expected life[11] on a rammed lining melting gray or malleable iron varied from 25 to 130 heats with an expected average of 100. Other information in the literature places the life at around 40 heats for steel melting. The greatest drawback in the way of more widespread use of rotary furnaces is that a satisfactory refractory is not available. When the cheapest fuel, powdered coal, is utilized the attack of the coal ash is severe. Moreover, at the temperatures necessary to melt malleable iron and steel, refractory life is short even with oil or gas firing. Spalling conditions are bad and the rotating action produces a cutting action that is hard on linings.

DIRECT-ARC ELECTRIC FURNACES

56. The direct-arc furnace is used in melting cast and malleable iron, steel, and alloy steel. Acid-lined furnaces are used for iron, both acid and basic for steel, and basic for alloys. The electric arc is in close proximity to the sidewalls; so careful design and skillful operation are necessary to avoid excessive destruction of linings. Commercially operated foundry electric furnaces vary in size from ⅛ to 80 tons capacity. The largest furnaces are used in production of steel ingots for wrought purposes. Most steel casting furnaces are in the size range of ½ to 3-tons capacity, while 3 to 6 tons are the most common sizes for the wrought electric steel industry. Cast iron furnaces vary in capacity from ¼ to 25 tons.

[10] Hamilton, W., *"Refractories in the Foundry and Furnace,"* FOUNDRY TRADE JOUR., *54*, 1936, p. 101.

[11] Faulkner, V. C., *"The Present Position of the Oil-Fired Rotary Furnace in England,"* FOUNDRY TRADE JOUR. *49*, 1933, p. 231.

Acid-Lined Furnaces

57. The bottom of acid linings such as used by the gray cast-iron industry is usually rammed ganister burned in with the electric arc. The side walls are of silica brick with about a 2-inch space insulated with sand or other silicious material between the bricks and furnace shell. The roof usually is made of silica brick. High-grade fireclay brick have been tried in roofs with fair success and the new super duty fireclay brick appear to have a place as a roof refractory. Fireclay brick appear to have some advantage over silica roof brick during periods of intermittent operation. Cold-patching of bottoms is done with ganister which is burned in similar to the original bottom. In hot-patching, some plastic clay is added to the ganister.

58. Lining life is quite variable depending on what is being melted. Bottom life is somewhat longer in melting steel than cast iron. With sufficient patching, bottom lives of nearly 10,000 heats have been reported on mixed melts of iron and steel. On the other hand, as low as 500 heats have been reported in melting malleable iron.

59. Side walls are susceptible to thermal spalling, especially on week-end shut downs. Iron oxide from the bath also attacks the silica. The attack on the roof is similar to that on side walls. Spalling action on the roof is most severe around the holes through which the electrodes pass. A change in design of furnaces which to date has not had wide application permits raising and swinging the roof to add the charge rather than using a charging door. Charging time has been reduced from ½ to 1 hour to 5 minutes, and a 30 per cent saving in refractories is claimed.[12]

60. The customary roof life in a 3-ton acid furnace making steel castings is about 200 heats, although as high as 1000 heats have been obtained. Wall life is about twice that of roofs. In general, the life is considerably longer in cast iron melting.

Basic-Lined Furnaces

61. Bottoms are made with tamped in dead-burned magnesite or periclase with suitable bond, frequently sodium silicate. They are burned in similar to acid bottoms. Patching is required after nearly every heat and is done with magnesite or sintered dolomite in much the same way as in open-hearth furnaces. The bottom portion of side walls is built of magnesite brick and the

[12] Moore, W. E., *"The Manufacture of Plain Carbon Steel in Top-Charge Type Furnace,"* TRANS. Elec. Soc., *68*, 1935, p. 43.

upper portion either of magnesite or silica brick. Low-iron magnesite brick, because of resistance to spalling, have found extended use. Silica bricks are used in door jambs and arches that are subjected to mechanical abrasion. Roofs are constructed of silica brick. Super duty fireclay brick have been tried and life about equal to silica bricks has been reported. Splashing of slag attacks the silica roof, and at times the temperature is high enough to cause dripping. As in the case of acid furnaces, greatest roof wear and spalling are around the electrode holes. Slag attacks the side walls. Upper portions, if made of silica, are more susceptible to attack by the basic slag than magnesite. Chrome brick are seldom used in electric furnaces because they are reduced and contaminate the melt with chromium. A thin layer may be used between the magnesite and silica brick in side walls.

62. Life of refractories is variable depending on the material being melted, the temperatures employed, and how often the furnace is heated and cooled, and how much attention is given to patching. A fair average for roofs is 100 to 150 heats, and about 300 for walls. The writer knows of one plant in which the roof life is considerably better than that of side walls. In this plant, the average roof life on a 3-ton per hour furnace over a period of years was about 150 heats while that of the side walls, constructed of silica except the bottom courses which were magnesite, was about 80. The management considered that re-lining was cheaper than patching. In the same plant the more continuous the operation the longer the refractory life. A roof life of 188 heats with 97 on walls was obtained on high production, but with intermittent operation as low as 74 heats on a roof and 57 on walls were secured.

63. A special type of electric furnace is used in making ferroalloys. Usually this is an open-top furnace, and the lining commonly is magnesite or periclase rammed in place with a binder and carefully burned in first with a wood fire and finally with the electric arc. A considerable portion of the lining is consumed during each heat owing to the high temperatures used and the corrosive nature of the slag. Patching of sides and bottoms is required after each heat. In some cases, acid and even carbon linings are used.

INDIRECT-ARC ELECTRIC FURNACES

64. Indirect-arc furnaces of the rocking and oscillating type were originally designed for melting of copper alloys but during

the past few years they have found some use in iron and steel foundries. When the charge is melted, the furnace is rocked so that the entire wall except the ends and that portion around the door and directly above is washed with metal. Heat is transmitted to the charge by radiation from the arc and walls and by conduction from the hot refractory during rocking.

65. Charging is intermittent and the refractories must be resistant to thermal shock. Joints must be tight to prevent metal penetration. Operating with the arc off center frequently causes refractory damage.

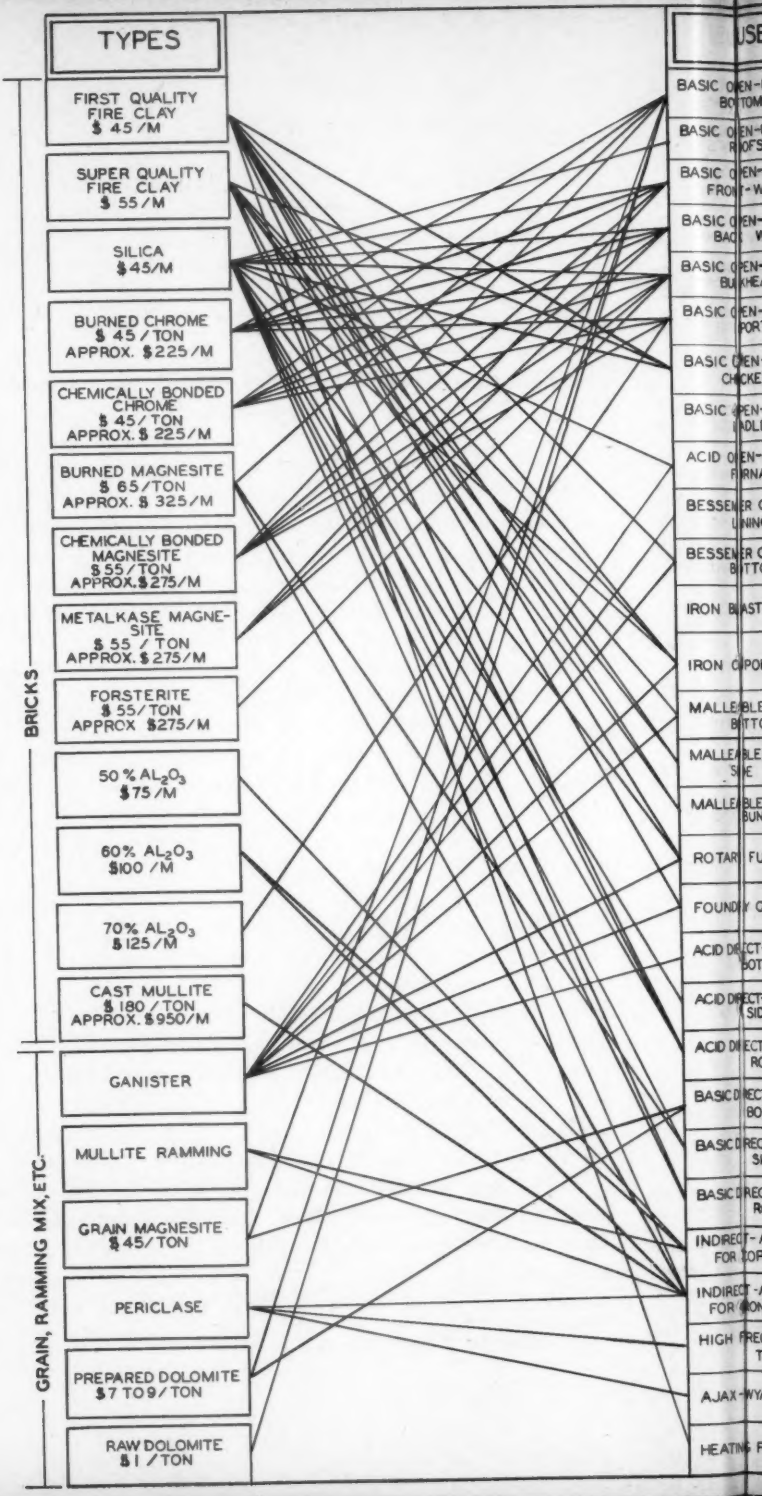
66. In melting copper alloys the temperature is usually 1800 to 2400°F. The lining is ordinarily blocks of high-alumina fireclay or rammed mullite compositions. The refractory life varies from 1000 to 3000 heats depending on the material melted and the care that is given to patching. Some operators prefer to reline a furnace before its life is exhausted in order to have better thermal insulation.

67. Refractory life is not so good in iron and steel melting. Nevertheless, the rocking furnace has found quite extensive application in making high-grade cast iron and in duplexing of cupola iron. In a few plants, alloy steel is being directly melted. Temperatures around 3000°F. are encountered in steel melting, and the refractory problem is complicated especially at ends and in the section above the door. Various types of refractories have been used, but generally the life is short.

68. Among the refractories used are mullite ramming mixes, crocks and brick, silica brick, and high-alumina brick. Brick linings of 25 to 50 heats are reported. Jordan[13] reported a life of 200 heats, about half cast iron and half steel, in an experimental furnace 16 in. in diameter by about 14 in. long using a specially prepared periclase ramming mix. Low-iron magnesite brick linings have been tried to a limited extent and have shown promise of longer life than acid-brick linings. However, the thermal conductivity of magnesite brick is so great that a good layer of insulation must be placed between the refractories and the furnace shell.

69. Special brick and ramming mixes are being tested and, while at least one composition shows excellent promise, enough tests have not been made to evaluate its true worth. Tests have indicated a long lining life from dense blocks of cast mullite. A lining life of about 400 heats about one-half of which were cast

[13] Jordan, L., *"Bonding Magnesite Linings,"* METALS AND ALLOYS, *3*, 1932, p. 22.


TYPES
BRICKS
FIRST QUALITY FIRE CLAY $ 45 /M
SUPER QUALITY FIRE CLAY $ 55/M
SILICA $45/M
BURNED CHROME $ 45 / TON APPROX. $225/M
CHEMICALLY BONDED CHROME $ 45/ TON APPROX. $ 225/M
BURNED MAGNESITE $ 65/TON APPROX. $ 325/M
CHEMICALLY BONDED MAGNESITE $ 55/TON APPROX. $275/M
METALKASE MAGNESITE $ 55 / TON APPROX. $ 275/M
FORSTERITE $ 55/TON APPROX $275/M
50 % AL_2O_3 $75/M
60% AL_2O_3 $100 /M
70% AL_2O_3 $125/M
CAST MULLITE $ 180 / TON APPROX. $950/M
GRAIN, RAMMING MIX, ETC.
GANISTER
MULLITE RAMMING
GRAIN MAGNESITE $45/TON
PERICLASE
PREPARED DOLOMITE $7 TO 9/TON
RAW DOLOMITE $1 / TON
USE
BASIC OPEN-HEARTH BOTTOM
BASIC OPEN-HEARTH ROOFS
BASIC OPEN-HEARTH FRONT-WALLS
BASIC OPEN-HEARTH BACK WALLS
BASIC OPEN-HEARTH BULKHEADS
BASIC OPEN-HEARTH PORTALS
BASIC OPEN-HEARTH CHECKERS
BASIC OPEN-HEARTH INSULATION
ACID OPEN-HEARTH FURNACES
BESSEMER CONVERTERS LINING
BESSEMER CONVERTERS BOTTOMS
IRON BLAST FURNACES
IRON CUPOLAS
MALLEABLE BOTTOMS
MALLEABLE ANNEALING
MALLEABLE BURNING
ROTARY FURNACES
FOUNDRY CUPOLAS
ACID DIRECT ARC BOTTOMS
ACID DIRECT ARC SIDEWALLS
ACID DIRECT ARC ROOFS
BASIC DIRECT ARC BOTTOMS
BASIC DIRECT ARC SIDEWALLS
BASIC DIRECT ARC ROOFS
INDIRECT ARC FURNACES FOR TOPS
INDIRECT ARC FURNACES FOR BOTTOMS
HIGH FREQUENCY
AJAX-WYATT
HEATING FURNACES

USE	REMARKS
IC OPEN-HEARTH BOTTOMS	AT LEAST 2 OR 3 AND POSSIBLY 10 X AS MANY CHROME AS MGO BRICKS USED. MGO + SLAG FOR PREPARING BOTTOMS; GRAIN MGO OR PREPARED DOLOMITE FOR LARGE REPAIRS RAW DOLOMITE FOR SMALL PATCHING.
IC OPEN-HEARTH ROOFS	INSULATION AND MECHANICAL CONTROL OF COMBUSTION AND DRAFTS INCREASED LIFE. BETTER LIFE CLAIMED FOR POWER-PRESSED BRICK.
IC OPEN-HEARTH FRONT-WALLS	AVERAGE LIFE ABOUT TWICE AS LONG WITH NEUTRAL AND BASIC BRICKS AS WITH SILICA. SILICA MOST WIDELY USED REPAIRS ARE EASY TO MAKE.
IC OPEN-HEARTH BACK WALLS	LIFE-MORE THAN DOUBLED BY USE OF NEUTRAL OR BASIC BRICKS WHICH ARE MOST WIDELY USED.
IC OPEN-HEARTH BULKHEADS	LIFE WITH METALKASE BRICKS AS HIGH AS 800 TO 700 HEATS; FORSTERITE, UN-BURNED MAGNESITE AND CHROME 450 TO 500 HEATS; SILICA 40 TO 125 HEATS.
IC OPEN-HEARTH PORTS	USING HIGH ALUMINA BRICKS, PORTS ARE WATER COOLED. PORT LIFE DEPENDS TO LARGE EXTENT ON DESIGN.
IC OPEN-HEARTH CHECKERS	SUPER QUALITY FIRE CLAY BRICKS RECOMMENDED FOR TOP COURSES AND FIRST QUALITY FOR LOWER COURSES INSULATION AND MECHANICAL CONTROL OF DRAFT AND COMBUSTION INCREASED CHECKER LIFE.
IC OPEN-HEARTH LADLES	RELATIVELY SOFT AND NOT HIGHLY REFRACTORY FIRE CLAY BRICKS USED.
D OPEN-HEARTH FURNACES	CONSTRUCTED LARGELY OF SILICA BRICKS. HEARTH OF SINTERED SAND OR GANISTER.
SSEMER CONVERTER LININGS	RAMMED MIXTURE OF GANISTER AND FIRE CLAY. GANISTER BLOCKS USED TO LESSER EXTENT.
SSEMER CONVERTER BOTTOMS	TUYERE BLOCKS OF FIRE CLAY SET IN POSITION WITH GANISTER AND CLAY.
N BLAST FURNACE	FIRE CLAY BRICKS USED. DENSE HARD-BURNED BRICKS RECOMMEND FOR HOT-TER PARTS.
N CUPOLA	SUPER QUALITY STIFF-MUD FIRE CLAY BLOCKS GIVE 2 OR 3 TIMES THE LIFE OF HAND-MADE BLOCKS. SILICA BLOCKS HAVE GIVEN GOOD SERVICE WITH HIGH-STEEL CHARGES. SILICA SAND AND FIRE CLAY USED FOR PATCHING. IN ENGLAND RAMMED GANISTER LININGS WIDELY USED.
LEABLE AIR FURNACE BOTTOMS	LIVES OF 50 TO 130 HEATS REPORTED WITH SUPER FIRE CLAY BRICKS. AVERAGE BOTTOM LIFE WITH RAMMED LINING OF SAND AND FIRE CLAY = 12 TO 17 HEATS.
LEABLE AIR FURNACE SIDE WALLS	LIFE OF SUPER FIRE CLAY BRICKS APPROXIMATELY DOUBLE THAT OF MEDIUM BURNED FIRST QUALITY BRICKS.
LEABLE AIR FURNACE BUNGS	LIFE OF BUNGS APPROXIMATELY DOUBLED IN MANY CASES BY USE OF SUPER FIRE CLAY BRICKS.
TARY FURNACE	BRACKELSBERG FURNACE: IN U.S. USE OUTER COURSE OF CUPOLA BLOCKS AND INNER LINING OF SILICA BRICKS. IN EUROPE RAMMED SILICEOUS LINING. BASIC LININGS TO DATE UNSATISFACTORY.
UNDRY CONVERTERS	IN U.S. FIRE CLAY BRICKS BETWEEN SHELL AND GANISTER RAMMED LINING. IN ENGLAND RAMMED GANISTER LININGS MOST WIDELY USED.
D DIRECT-ARC ELECTRIC BOTTOMS	SINTERED WITH ELECTRIC ARC.
D DIRECT-ARC ELECTRIC SIDES	
D DIRECT-ARC ELECTRIC ROOFS	SUPER FIRE CLAY BRICKS APPEAR TO HAVE A PLACE AS ROOF REFRACTORY BUT ENOUGH SERVICE DATA ARE NOT AVAILABLE TO DRAW DEFINITE CONCLUSIONS.
IC DIRECT-ARC ELECTRIC BOTTOMS	RAMMED WITH BOND SUCH AS SODIUM SILICATE AND BURNED IN.
IC DIRECT-ARC ELECTRIC SIDES	MAGNESITE MUST BE USED IN LOWER COURSES IN UPPER COURSES MAGNESITE LESS ATTACKED CHEMICALLY THAN SILICA. FOR HIGH-QUALITY STEEL, ENTIRE MGO WALLS RECOMMENDED
IC DIRECT-ARC ELECTRIC ROOFS	ABOUT EQUAL LIFE CLAIMED FOR SILICA AND SUPER FIRE CLAY, BUT LATTER HAVE NOT BEEN USED WIDELY ENOUGH TO DRAW DEFINITE CONCLUSIONS.
RECT-ARC ELECTRIC OR COPPER ALLOYS	LONG LINING LIFE IN ALL CASES. MONOLITHIC LININGS EASY TO PUT IN.
RECT-ARC ELECTRIC R IRON AND STEEL	BEST LIFE FROM CAST MULLITE BLOCKS, RAMMED LININGS OF SPECIALLY PRE-PARED PERICLASE. AND LOW-IRON MAGNESITE BRICKS.
H FREQUENCY INDUC-TION	FOR SMALL FURNACES USE CRUCIBLES. BEST SERVICE ON LARGE FURNACE FROM RAMMED PERICLASE SINTERED IN PLACE.
X-WYATT	FOR YELLOW BRASS, RAMMED LINING OF ASBESTOS CEMENT AND FIRE CLAY. BEST RESULTS FROM RAMMED PERICLASE LININGS ON HIGH-MELTING COPPER ALLOYS, COPPER, NICKEL, ETC.
TING FURNACES	LIGHT-WEIGHT BRICKS RECOMMENDED FOR SIDES AND ROOFS OF INTERMITTENT-LY OPERATED FURNACES.

FIG. 1 — REFRACTORIES USED IN THE FOUNDRY INDUSTRY

iron and the rest plain carbon steel was obtained in a 350-lb. furnace. The chief disadvantage of these blocks outside of cost is the difficulty of cutting them to shape. Lack of a suitable refractory is retarding the progress of rocking furnaces in steel melting.

70. In melting iron and in duplexing where such high temperatures are not encountered, lining life of 300 to 500 heats has been reported using a rammed mullite lining properly burned in.

71. Slags, except a little iron oxide and the like, are rarely encountered in the indirect-arc furnace, so the chief refractory requirements is ability to withstand high temperatures without fusion or deformation. Resistance to spalling is necessary if cold charges are melted. The refractories must have sufficient mechanical strength to withstand charging shocks.

HIGH-FREQUENCY INDUCTION FURNACES

72. A variety of metals, alloys, and steel is being melted in high-frequency furnaces. The capacity varies from as low as 1-lb. in laboratory furnaces to 5-ton commercial furnaces for steel melting. The lining must be impervious to metal penetration; so it must be dense and free of cracks. To secure good electrical efficiency, the walls of the container should not be too thick. In small furnaces, prefired crucibles are usually used. In larger furnaces linings are invariably rammed in place. A common method of preparing a lining comprises ramming it in place around a steel core, and sintering by induced electrical heating.

73. Most commercial furnaces operate with a basic lining. Electrically sintered magnesite is most widely used. Dead-burned magnesite shrinks excessively and it is difficult to obtain a lining with freedom from cracks. Magnesia-alumina linings also are used. Acid linings are less widely employed. Rammed silica and pure zircon sand have been used. Recently, calcined cyanite rammed linings have been introduced. Lining life is variable depending on the materials being melted.

INDUCTION ELECTRIC FURNACES

74. The vertical-ring high-frequency furnace is used for melting brass and presents some unusual refractory requirements. To obtain high electrical efficiency, the refractory lining between the metal and primary coil must be thin, but it must be impervious and

free of cracks because penetration of metal causes short circuiting. Diffusion of metal into the refractory also decreases electrical efficiency. The metal in the "V"-section should be maintained at 400° to 500° F. above the pouring temperature.[14] In melting high-zinc brasses, zinc oxide is gradually built up in the loop, and after long runs furnaces may choke up.[15] The action of the metal is not rapid enough to cause much erosion, although high melting point alloys cause some wear.

75. For melting yellow brass a rammed lining of asbestos cement and fireclay gives good service. A total of 8 to 10 million pounds has been obtained from a single lining.[16] This lining, however, is not satisfactory for higher melting point alloys.

76. Difficulty has been encountered in obtaining satisfactory linings for alloys melting at temperatures of 2500° F. or above especially for those containing over 3 per cent of lead. Pre-formed refractory clay linings have been used but troubles from porosity and thickness frequently were encountered. One manufacturer is making pre-formed shapes of high-alumina clay, and better preformance is claimed. Rammed linings of electrically sintered magnesite bonded with sodium silicate are used for melting high-copper alloys, nickel brass, and copper. Life is about 1/10 to 1/4 that of asbestos-fireclay linings for yellow brass. In melting nickel or its alloys with a magnesite lining, the lining life is given as 50 to 250 heats[17] and 600 when melting copper.[18]

HEATING FURNACES

77. Annealing and normalizing furnaces and the like do not present a severe refractory problem because they ordinarily do not operate at high temperatures; a range of 1200 to 1800° F. covers most furnaces of this type. The chief refractory requirements are resistance to abrasion on the bottom and to spalling on the roof and walls. Formerly these furnaces were built almost exclusively of fireclay brick. Today many furnaces, except for the bottom, are built entirely of light-weight brick. Low heat capacity is the fea-

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[14] St. John, H. M., *"Refractories for Brass Foundry Furnaces,"* TRANS. Amer. Foundrymen's Assn., *36*, 1928, p. 439.

[15] Gillett, H. W. and Mack, E. L., *"The Electric Brass Furnace Refractory Situation,"* JOUR. Amer. Cer. Soc. 7, 1924, p. 288.

[16] Adams, Wm., Jr., *"The Ajax-Wyatt Induction Furnace,"* TRANS. Elec. Soc., *57*, 1930, p. 462.

[17] Campbell, D. F., *"Recent Developments in Electric Furnaces,"* JOUR. Inst. of Metals, *41*, 1929, pp. 37-72.

[18] Robiette, A. G., *"The Low-Frequency Induction Furnace and Its Scope,"* METALLURGIA, *3*, 1931, p. 175.

ture of light-weight brick that makes them particularly advantageous for heating furnaces. After week-end shut downs they can be brought to operating temperatures in a shorter time and with less fuel consumption than those constructed of dense brick. The resistance to spalling of light-weight brick is not so good as that of dense bricks made of the same materials.

78. Fireclay refractories are widely used in reheating furnaces. Resistance to spalling is required in walls and roofs. Bottom refractories must resist abrasion and fluxing action of scale. Bottoms are constructed of fireclay or silica brick or plastics, usually of a chrome base. Silicon carbide and corundum bottoms have also been used.

79. Forging furnaces are usually constructed with fireclay roofs and walls. Bottoms are of fireclay brick or plastics. A few forging furnaces, except bottoms, have been constructed of light-weight brick.

TRENDS IN REFRACTORIES AND THE EFFECT ON METALLURGICAL INDUSTRIES

80. In discussing the newer refractory developments, it appears advisable not to limit the discussion to iron and steel and the foundry industries. For that reason, mention is made in some instances of applications not covered in the earlier part of this paper. It should also be pointed out that a brief paper of this type can not cover all refractory developments in detail. Some manufacturer or consumer may find that a given refractory fits his purpose ideally but the same material may be unsuited in another plant using a somewhat different process or procedure. In the foregoing discussions on individual types of furnaces the effect of improved refractories on furnace life and performance was stressed. The discussion following relates to individual refractory improvements.

81. The past decade has seen the introduction of the low-iron magnesite brick which possesses superior resistance to thermal spalling over the older high-iron type. It also has somewhat better load-bearing ability at high temperatures. It has found wide use in open-hearth, electric, and lead furnaces. The cost is the same as for high-iron bricks.

82. Chemically bonded or unburned magnesite brick is also a new product. Perhaps the chief advantage over burned brick

lies in the fact that they cost $10 per ton less, although they possess some superior qualities to most burned brick. For example, resistance to thermal spalling is high. Brick of this type are of two classes. One uses a refractory chemical bond and is formed under high pressure (hydraulic) with careful grading of particle size. Patents issued to one manufacturer indicate that the bond is chrome ore, clay, and sodium acid sulphate. The other class is an improved Metalkase brick and comprises a chemically bonded brick with a steel cover or shield. This differs from the older type of Metalkase brick in which grain magnesite was packed in a metal cylinder or tube. Unburned magnesite brick have found extensive use in basic open-hearth furnaces not only below the slag line but to a certain extent have replaced silica brick in walls. They have also given good service in soaking pits. Other uses are in rotary cement kilns, copper converters and refining furnaces, and in the form of suspended roofs in copper reverberatory smelting furnaces.

83. Recently an unburned chrome brick made similarly to unburned magnesite brick has appeared on the market. Chemical analysis published by one manufacturer shows approximately 30 per cent each of Cr_2O_3 and MgO, 18 per cent of Al_2O_3, 12 of FeO, and 5 of SiO_2. Its properties are such that it is used as a substitute for burned chrome and magnesite brick. The cost is the same as for the fired product. In open-hearth furnaces, it finds use above the slag line for construction of front, back and end walls, and ports. Like unburned magnesite it is quite resistant to thermal spalling.

84. Another new basic brick is forsterite comprising essentially magnesium oxide and silica in a molecular ratio of 2:1. Resistance to thermal spalling is about the same as that of low-iron magnesite, and the strength at high temperatures is superior to either magnesite or chrome brick. The widest use to date is in open-hearth bulkheads, and in the copper industry. There are several installations of forsterite brick in roofs of copper holding furnaces, and they are also being used to line rotary kilns.

85. Improved fired chrome and Kromag brick fired to higher temperatures and chemically balanced by addition of MgO to eliminate low fusion magnesium silicate minerals have given better life and service in open-hearth furnaces than the older chrome brick.

86. A cast brick known as "Siemensit" was introduced in Germany 4 or 5 years ago. It is said to contain 20 to 40 per cent of Cr_2O_3, 25 to 45 per cent of Al_2O_3, 18 to 30 per cent of MgO, and

8 to 14 per cent of other ingredients. The writer knows of no installations of it in the United States.

87. The most important development in strictly fireclay brick of the past decade is super duty fireclay brick made from flint fireclays. They are characterized by high density and volume stability, and have the best spalling resistance of high refractory alumina-silica refractories. They are widely used in open-health checkers, glass-tank checkers, roofs of heating furnaces, blast-furnace stoves, cupolas, and in roofs of electric melting furnaces. The cost is $10 per thousand higher than first quality fireclay brick.

88. High-alumina brick in the past suffered from the drawback of volume instability or shrinkage on continued use at high temperatures. Volume stable brick have been developed by prefiring at high temperature a large portion of the raw mixture. Grain sizing and pressing under high pressures contributed to such properties as low porosity, strength, low shrinkage, and resistance to spalling. One of the widest uses is in rotary kilns for Portland cement, dolomite, and lime. They are also used in boiler installations, in the glass industry in ports and regenerator wall construction and in checkers, in center walls in zinc distillation furnaces, and in malleable air furnace bottoms.

89. Silica brick were formerly all made with a lime bond. Recently one manufacturer introduced a barium-type bond. Another manufacturer introduced power pressing.

90. There are innumerable new so-called super-refractory brick, most of which aim at a high mullite content. In a paper of this nature it is impossible to discuss them in detail. Their sales are increasing and they are deserving of the place they are taking in the metallurgical and ceramic industries. They find widest uses in the electric furnace and glass industries.

91. No discussion of refractory trends and developments is complete without consideration of insulation which was discussed in considerable detail in the section on basic open-hearth furnaces. Insulation has not only resulted in fuel savings but in most instances improved refractory life also resulted. With insulation, operators will undoubtedly attempt to attain higher temperatures, and this will again put greater demands on refractories.

92. The production of light-weight brick of sufficient refractoriness and strength for use as a structural unit has been a boon to intermittently operated furnaces in which the heat loss by storage was large.

93. Not only have new refractories been developed but improved manufacturing technique is being used on many old ones. Careful grading and controlling the grain size of the refractory mix has resulted in better workmanship and refractories of higher density and better physical properties.

94. Increased use of power-pressing has resulted in brick of more uniform texture, freedom from molding imperfections, and lower porosity. In pressing refractory materials at high pressures so-called pressure cracks tend to form by virtue of air entrapment. A lamination or actual crack in the brick may result. Pressure cracking may be eliminated by removal of the air (de-airing) prior to or during pressing. In power-pressing this may take the form of evacuating the mold box or of displacing the air by a gas such as butane which is easily condensed on application of pressure. In extrusion methods, vacuum is applied to the chamber between the pug mill and the extrusion auger. De-airing has improved power-pressed brick and has permitted higher pressures. Employment of vacuum de-airing in production of extruded stiff-mud bricks has also resulted in a product of better texture, density, and freedom from imperfections.

95. As previously mentioned, many basic and neutral brick are now unburned, but in all other cases the tendency is to increase firing temperatures to secure products that are better physically, and to effect chemical union and physical transformations.

96. A noticeable advance during the past decade is the uniformity and trueness to size. Tolerance has been decreased, and this has resulted in better furnace design and economy of operation.

97. Refractory mortars and cements have been greatly improved, and this in no small measure has contributed to better life and performance of refractories. Improved patching and ramming mixes have also been developed. However, the number and complexity of materials are such that a complete discussion can not be given in this paper.

DIAGRAMATIC SUMMARY

98. Fig. 1 tabulates the most important refractory bricks, ramming mixes and the like used in principal parts of many foundry furnaces. The aim has been to make the chart as complete as possible, but to hold it within reasonable size and without inclusion of too lengthy remarks. To use the chart to best advantage reference should also be made to the discussions of the various furnaces.

Only the most commonly used types of refractories are indicated in the chart. Discussion of less frequently used types are often given in the discussion. In most cases, the prices in the column on refractory types are those currently quoted in trade journals for 9-in. straight brick. In a few instances, where prices are not currently quoted, prices were obtained from manufacturers. Special shapes cost more, but the quoted prices can be used for comparative purposes. The cost of ramming mixes and the like vary greatly with composition, refractoriness, etc.; so no attempt was made in many cases to present generalized costs.

(*Discussion Begins on Page 281*)

DISCUSSION

J. A. BOWERS[1]: I would like to ask Mr. Lowe if he has ever tried reversing the order of the lining in the melting zone; in other words, laying the cupola block next to the shell and lining the melting zone with 9-in. standard straights.

MR. LOWE: We have started with the 9-in. straights, and then tapered off with splits, or sometimes start with the cupola blocks, turn them flat, wedge them in, and taper off with the 9-in. straights and the splits.

I would like to ask a few questions. How does the heat conduction of cupola refractory material vary with the thickness of the lining? The thicker your lining, the more insulation you have on the outside. How does that affect the burning out of your cupola?

MR. SULLIVAN: That depends on other conditions. If all other conditions are equal and the insulation is increased, it gets hotter on the inside and the lining may burn out. But on the other hand, if the insulation keeps the heat inside, it may be possible to get the same temperature on the inside with the use of less fuel.

That is strictly the case in the open-hearth industry. Insulation has increased, and not decreased refractory life, largely for the reason that the same bath temperature can be obtained by burning less fuel, and if less fuel is burned the cutting action of the gases is decreased. Insulation, also keeps the gases from coming up between the bricks.

A. H. DIERKER[2]: I would like to mention one point. That is, in the cupola, you have a circular melting furnace, in such a case the simple formula for heat conduction will not strictly apply, because the area at the cold side is much greater than the area at the hot side, and the thicker your lining the greater the discrepancy. This is a factor that will have to be considered.

CHAIRMAN C. E. BALES[3]: In our discussion our committee has several questions to ask. First, perhaps there is somebody here now who has had some experience with the use of monolithic linings in the cupola. If they have, we would certainly like to hear about it.

H. RAYNER[4]: At the shop course, the opinion was that monolithic linings were satisfactory provided you had time enough to dry them. Someone said that the European practice was quite satisfactory.

On weekends, in our own particular foundry, we used the monolithic lining. We had at least 20 hours to dry it, and we found that it is as good as the regular refractory, but it certainly has to be dry. It takes about 24 hours to dry through the entire depth of the monolithic lining.

CHAIRMAN BALES: There is one point Mr. Lowe raises, and that is, the use of a sand-slinger for applying a monolithic lining. I do not under-

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[1] American Cast Iron Pipe Co., Birmingham, Ala.
[2] Engineering Experiment Station, Ohio State University, Columbus, Ohio.
[3] Ironton Fire Brick Co., Ironton, Ohio.
[4] Chrysler Corp., Detroit, Mich.

stand just how he is going to do that. If he will give us some ideas, I would like to give it some study.

MR. LOWE: We have experimented some with the sand slinger, using different refractory mixes. These mixes were applied to a half section built up of cupola block. As yet we have not tried this method in a regular cupola.

Another question, is the length or the severity of the heat the determining factor as to the amount of burning in the cupola lining? What I mean by that is, if you run the cupola to capacity, say 18 to 20 tons an hour for 8 or 10 hours, will that burn out more or less than the same cupola running 10 tons per hour for 18 hours?

W. A. O'BRIEN[5]: I believe that all other conditions being equal, it is incessant operation rather than the tonnage melted that burns out the cupola.

MR. LOWE: Is it correct that a cupola will stand a longer heat on cold blast than on hot blast?

MR. O'BRIEN: Other conditions being equal, your cold blast will not burn quite so deep as the hot blast, although it will burn higher, and it will also cause greater bridging above the tuyeres, although the hot blast will burn deper but not as high in the melting zone.

MR. LOWE: Can one use a periodic slag analysis in determining the detrimental reaction on the lining?

MEMBER: I believe that the periodic slag analysis will reveal to a very large extent the conditions occurring in periodic intervals in the cupola, as to the proper operation. Even if the cupola is operated on normal practice, there are reactions occurring which will prompt an off-condition, so to speak, due to an excess oxidation, which will eventually determine the amount of refractory material. However, these determinations are rather difficult to make, or are not very easy to accomplish in a short period of time to be of great value.

MR. LOWE: Is it advisable to watch the slag color relation?

MEMBER: Well, the color relation sometimes fools you quite badly. It is more or less necessary to be dependent on the chemical analysis rather than the color observation to give you the correct result.

Slag analysis is a subject that has been neglected for too long a period of time, and if carried out on a large scale with more information than we have today, it would be of great benefit.

MR. LOWE: I know the blast furnace men are quite good at judging by the color of the slag.

MR. RAYNER: The difference between the amount of slag and the amount of lining is so great than I think the effect of the erosion of the lining on the analysis of the slag would be very slight.

MR. O'BRIEN: Mr. Lowe, I notice in your slides that you have a slight overhang above the tuyeres. Is that to prevent, to some extent, bridging,

[5] Electric Auto Lite Co., Fostoria, Ohio.

less severe burning, and possibly to get better cupola operation? That is my opinion, and I just wondered if that is yours.

MR. LOWE: Yes.

G. OLSON[6]: Mr. Lowe mentioned the tuyere area ratio as being four to one. I was wondering if Mr. Lowe has used a certain relationship between air pressure and the diameter of the cupola?

MR. WINTE[7]: In one particular cupola, 49-in. the pressure runs from 12 to 15 ounces. That depends on production.

MR. OLSON: Have you found any difference in the life of your lining when you change your pressure?

MR. WINTE: Well, in this case, it seems to be an iron that is very hard on the lining and I cannot say what difference the pressure would have on the lining in this cupola, because it is always run at full blast, within those limits, and it has never been run at low blast.

MR. BOWERS: I think I can answer that question. Of course, our cupola is much larger than the one under discussion, 72 x 102 in. Our blast pressure varies 20 to 35 ounces, and when we blow around 30 to 35 ounces all day, the lining burns out much worse than when it is blown around 20 ounces.

MR. LOWE: We have never been up to that range, so we have not had that marked effect.

MEMBER: What is the effect of tuyere design on the life of the lining?

MR. RAYNER: We had quite a lot of experience with various types of tuyeres and finally adopted "Clutts" tuyeres. Previously we had a continuous tuyere of too large an opening, or too low tuyere ratio. In the "Clutts" tuyeres, the openings were smaller, with a higher ratio. This improved our practice by using less coke and prolonging the life of the lining. Each cupola has a proper tuyere ratio for its operation under set conditions. The type of blower, kind of material used in the charges, and the quality of coke all effect the selection of the proper tuyere ratio which, if not right for all conditions, will cause the blast to be too penetrating or too open. In the latter case, it will allow the air to go up the sides of the cupola and burn out more of the refractory lining. Concluding, I would say that the selection of the proper tuyere ratio has a great deal to do with the life of the lining.

MR. O'BRIEN: I would like to ask Mr. Lowe if he has ever experimented with a variation in the burning effect on the lining of the cupola with the tuyere area relation in regard to diameter?

MR. LOWE: Not very much.

MR. O'BRIEN: I also have noticed, through periodic slag analyses, that we have less oxidization in the cupola.

MR. DIERKER: In covering as much ground as Mr. Sullivan has in his paper, I do not doubt that a few mistakes are bound to creep in. However,

[6] National Founders' Association, Chicago.
[7] Fairbanks-Morse Co., Beloit, Wis.

I do not feel that we ought to pass this up without at least mentioning them, so that corrections can be made before the final printing.

On page one, I think, operators of large steel foundries would be quite surprised to learn that the basic open-hearth furnace is not a foundry furnace.

In paragraph 63, regarding special electric furnaces for making alloys, I think you will find a great many of those are lined with carbon for special types of alloys.

MEMBER: Mr. Sullivan mentioned the fact that super-duty brick at very high temperatures was found most successful in open-hearth checkers. During the past few years, we have found just the opposite to be true. We have never had occasion where spalling was found on checkers where second-rate brick was used.

J. GRENNAN[8]: There is something I would like to ask in regard to the refractory. The speaker referred to improved brick, but as I gathered it, the improvement is almost entirely mechanical. The brick is harder rammed and is a better shaped brick, but he said practically nothing about the chemistry of the firebrick. Is there anything about the chemistry of the brick that has been improved?

MR. SULLIVAN: You are probably referring specifically to the super-duty fireclay brick. They are made largely from flint fireclays, and have higher refractoriness than bricks made from more plastic clays. Their P.C.E. value in all cases exceeds Cone 33.

L. C. HEWITT[9]: The problem is mechanical rather than chemical. It is true, of course, that the P.C.E. value of the brick is higher. However, the actual chemical make-up of the first quality brick in super-heat-duty brick may be 45 per cent alumina, or less than that. It is more mechanical than chemical.

FRED A. HARVEY[10]: As I understood the question, it applied more to the normal high-heat-duty fireclay brick than to the super-duty fireclay brick. I believe Mr. Sullivan claimed for the manufacturers, much to our gratification, an improvement in high-heat-duty fireclay brick. I believe an improvement has actually taken place, although not through changes of the chemical composition of the clays due to purification or other means. Very little has been undertaken by manufacturers in the way of purification and what has been done is not, so far, very practicable. We do know more about the clays we use through the study of the various types of clay which occur in our clay deposits. By a study of these types of clays, we are able to select and recombine the clays in the brick mix better today than we were a few years ago. We are also learning a great deal about the effect of various sizings of the clay grains in the brick mix, and that variations in grind, and grain size distribution bring about considerable changes in the properties of the brick. While, most of

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[9] Laclede-Christy Clay Products Co., St. Louis, Mo.
[10] Director of Research, Harbison-Walker Refractories Co., Pittsburgh, Pa.

us, have not gone to the extent of sizing to 1/2 dust fractions and then recombining these fractions as we would like to do, were it not for the cost of manufacture, we have learned how to vary our grinding procedure so as to produce grain sizings which give a much better proportion of the various fractions than we normally obtained before we had the information. This has resulted, in a normal high-heat-duty fireclay brick, of increased resistance to spalling. The apparent resistance of a mixture of clays to spalling varies with the sizing, but the actual P.C.E. is unchanged. An increase in effective refractoriness improves the brick in its resistance to slag action and to loads at high temperatures, and increases the actual temperature which it will withstand in furnace operation.

I believe the improvement of high-heat-duty fire brick has been almost entirely on the mechanical side. A few years ago the bulk of the fireclay brick produced was made by the old hand made process. Today most of the production is by machine with power press or auger machines. It is on account of this machine method of manufacture that we are able to take advantage of our increased knowledge of the effect of sizing of the various fractions of the brick mix.

CHAIRMAN BALES: Mr. Bowers has presented an interesting refractory specialty. Are there any questions you would like to ask of him regarding the behavior of this brick, or whether or not you think it would be applicable to your own cupola operations?

MEMBER: For about a year and a half we have been using a spout brick very similar in design to that shown in Mr. Bowers' paper. By a rather unusual coincidence, we have been getting an average life of about 4,800 tons, whereas I note that Mr. Bowers says he is getting apparently a minimum life of about 4,500 tons. Our block differs in that it has a plain blunt end instead of a male and female joint. We find that we get better service from our blocks in different parts of the trough. From the cupola spout to the slag notch we find that the blocks do not stand up as long as from the slag notch to the end of the spout. I was wondering if that checks with the experience Mr. Bowers has had, and also if he found it necessary to change individual blocks. Is not it a fact that you have difficulty in extracting just one or two blocks?

MR. BOWERS: I would like to say first that since this paper has been written we are getting much longer life from these tile. In answer to the question, you will remember from the first slide I had, part of the iron trough serves all three of the cupolas, and the rest of it just one. As is natural that is the place that would burn out first, therefore it could be easy to remove these end tile. However because of the long life of the trough, and in order to avoid unnecessary risk, we have in the past simply renewed the entire trough when it began to show signs of spalling or wearing in any one place. We do not use these tile from the cupola spout to the slag notch.

CHAIRMAN BALES: Another question on our schedule. Is it possible to reduce silicon from sandstone used in the melting zone of a cupola?

MR. O'BRIEN: I have used silica stone in lining my stack for the past

5 years, and have had wonderful success, but I would like to know if there are any others here who have any definite proof of whether they have a reducing condition in the cupola that will cause hard spots in castings due to the effect of the silica lining in the cupola.

MEMBER: We used something along the same idea and learned that there was comparatively no difference in the slag, but a noticeable difference in the castings. We did get a slight difference in the chemical analysis of the metal. With the alumina lining in there, we had about 5.0 per cent more silica loss than we had with firestone lining. That was the only difference.

MR. DIERKER: I do not know whether or not I was the guilty party in starting this question. I happened to mention it in the paper* we gave last year. It had no reference, however, to the lining material, merely to the slag.

I think there is little question that silica can be reduced to silicon in the cupola. We have other evidence than the actual analysis of materials going into the cupola and the materials coming out. We know that silica is not particularly hard to reduce, especially from the highly silicious slag. We have proved that easily in experience with acid open hearths, acid electric furnaces, and even the malleable air furnace. In the paper presented last year, I believe I did mention something about castings in certain plants becoming unmachinable when the silicon content of the slag increased. It was not intended to infer from that that silicious slag caused hard spots in the casting. The only aim in that statement was to emphasize the importance of slag control for uniform cupola operation, and I hope that no one gets the impression that the hard spots are caused by any particular lining material. The lining may, or may not cause this trouble.

CHAIRMAN BALES: There have been quite a few foundrymen claiming that they do have that difficulty, and that is why this question was put in here, at the request of foundrymen who thought there would be some people here versed in the chemistry of this material at these high temperatures and in an intensely reducing atmosphere.

Do fire clay shapes give better service than silica brick in some electric furnace roofs? There have been quite a few operators during the past few years using clay roof brick instead of silica roof brick.

MR. LOWE: I do not know from actual experience, but last year I visited the International Nickel Company at Huntington, W. Va., and in examining the top there, I was asked how many heats we had. I told the gentleman about a half dozen, and he told me he had 75 or 80, because the top was made of highly refractory clay brick. The reason he went to that type of brick in preference to the silica brick is that he had a full operation, in heating and cooling. He got away from the spalling. He also had it on the side walls. I might add that he had a magnesite bottom that had been in for 11 years.

MR. DIERKER: In a small laboratory furnace, operating very inter-

* *Slags and Gases in Cupola Operation*, TRANS. A.F.A., Vol. 43, pp. 404-410.

mittently, always starting from a cold charge and never running perhaps more than one heat at a time, we found that a fireclay roof was far superior to a silica brick roof, due to the fact that there was far less spalling, and I understand that other manufacturers operating on smaller furnaces, where the stress on the roof is not particularly high, have been quite successful with that type of roof.

CHAIRMAN BALES: I wonder if that is due particularly to depression conditions, or whether it would be a general thing regardless of the depression. Some of these electric furnaces have been operated intermittently during the past few years. On the other hand, if they are kept hot regularly in boom times, the silila brick would work better.

DR. HARVEY: I think Mr. Sullivan answered the question pretty well in his paper. It depends on the operation. If the operation is sufficiently continuous, the silica gives better service. If it is discontinuous, then you will have unusually severe spalling in the silica brick, and the fireclay or super-fireclay brick will give better service.

CHAIRMAN BALES: What is the best type of refractory for the rotary, powdered-coal-fired type of furnace?

W. R. BEAN[11]: The question of lining for Brackelsberg furnaces is a large one, and it is probably not possible to cover it adequately this evening. However, a few statements can be made, based upon experiences over a period of about two years in the operation of Brackelsberg furnaces with brick linings.

The practice which we recommend in the operation of the Brackelsberg furnace is to place a clay brick course next to the shell, that being a standard cupola block 6-in. thick. For intermittent operation on gray iron, a high quality clay brick lining may be used with fair success and with a fair cost of lining per ton of product. The best results have been obtained from the silica brick lining 6-in. thick, installed inside of the clay brick lining. This gives what we term 6-in. permanent lining against the shell, which lasts many months and for many thousands of tons of metal.

The silica brick lining life depends upon the temperature at which the furnace is operated, and the temperature at which it is necessary to operate depends upon the material and the nature of the charge that is being melted and the nature of the castings into which this material is being poured.

We have a lining in an 8-ton furnace which has taken over 1800 tons of gray iron, and is still in service. That is the maximum life which we have had from any lining. It is not our practice, to patch or to do anything in the way of maintenance on these linings, except to renew the cone ends. That is, a Brackelsberg furnace lining, or the shell, is made up in three sections, the front and rear cones, and the central cylindrical portion. Those cones can be relined at intervals if there is occasion, and they do not last quite so long as the cylindrical, or the body portion of the lining.

When it comes to metal that is tapped at 3000° F., and a great deal

[11] Whiting Corp., Harvey, Ill.

of the metal today—copper-silicon-steel—is being tapped at that temperature, the lining life is much shorter, and is of the order of 60 to 90 heats of 6 or 8 tons, giving around 350 to 500 tons of metal from a lining.

It is therefore our experience that the silica brick lining for most purposes is the best, will show the lowest cost, and the longest life.

Apprenticeship

By Franklin R. Hoadley,* Ansonia, Conn.

Abstract

A recent survey of some 170 foundries showed that less than 3 per cent were training mechanics or junior executives, while 17 per cent reported a shortage of skilled workers. In 1935 over 46 per cent of the employees were over 45 years of age. This failure to provide for future needs demands more than mere talk about training. While national organizations are providing plans and instructional material, the direct plans must be fostered by local organizations and individual plants. Basic necessities for any successful scheme are hiring of boys properly qualified, maintaining their interest in the work, and providing for both practical and related material instruction of the best type. The author discusses the details of the training plan of his company, and in conclusion stresses the need for having the superintendent and foreman as eager to obtain good apprentices as they are to get good castings.

1. Fortunately, for all of us, there is an awakening to the shortage of skilled labor. Trade journals contain more and more material regarding apprentice training. Meetings of industrial associations are devoting more time to discussion of the subject. If one could have access to a clipping service covering the number of written and spoken words on apprenticeship, it would be apparent that many individuals are alive to the vital importance of training mechanics.

Statistics Show Vital Need for Training

2. There is a serious question, however, as to whether this increased interest has been really converted into action. A recent letter from the National Founders Association to its members states that, "As a result of investigation into labor needs and sources, in which you may have helped, we have learned that less

* Vice President, Farrel-Birmingham Co.

Note: This is the first of three papers presented at a session on Apprentice Training at the 1936 Convention of A. F. A. in Detroit, Mich.

than 3 per cent of 168 plants visited were training mechanics or junior executives, and that even six months ago, 17 per cent of these plants reported a shortage of skilled workers. You will note from the table below, that an increasing number of foundry employees are moving into the advanced age brackets." The table referred to shows that in 1920 only 25 per cent of foundry employees were over 45 years of age. In 1930 this figure had increased to 34.8 per cent. In 1935, over 46 per cent of the employees were over 45 years of age. In other words, during the fifteen-year period from 1920 to 1935, the number of foundry employees who were older than 45, had increased more than 21 per cent. These few statistics prove our failure to provide for future needs.

TRAINING—WHOSE RESPONSIBILITY?

3. The president of our association, Mr. Avey, has said, "The subject of apprenticeship is as old as the hills and as Mark Twain remarked about the weather, 'We all talk about it and no one does anything about it.' While we might preach from now to doomsday on the shortage of men, the vital need for training apprentices and all that, the average foundryman feels that it is not his direct responsibility, and it is hard to make him see his gain if he does train apprentices, or his personal loss if he does not. At the same time, I think there is within all of us an instinct, moral urge or what you will, that provides a distinct pleasure when we assist in educating the next generation."

APPRENTICE TRAINING AN ANCIENT PROBLEM

4. There is much meat in Mr. Avey's statement. The subject of apprenticeship indeed approaches the age of the hills. The Encyclopedia Britannica tells us that, "it arose in the middle ages, and formed an integral part of the system of trade gilds and corporations by which skilled labourers of all kinds sought protection against the feudal lords, and the maintenance of those exclusive privileges with which in the interests of the public they were favoured. The medieval universitas or corporation included both such as were entitled to practise and teach and such as were in course of learning. The former were the masters, the latter the apprentices." And we learn that the term "apprentice" applied with equal dignity to "such as were being taught a trade or a learned profession, and even to undergraduates or scholars who

were qualifying themselves for the degree of doctor or master of the liberal arts.

5. During the middle ages the term of apprenticeship was seven years, and this period was thought no more than sufficient to instruct the learner in his profession, craft or mystery under a properly qualified master, teacher or doctor—for these names were synonymous—and to reimburse the latter by service for the training received. After this the apprentice became himself a master and a member of the corporation (universitas), with full rights to practice the business and to teach others in his turn; so also it would seem that undergraduates had to pass through a curriculum of seven years before they could attain the degree of doctor or master in the liberal arts. On the continent of Europe these rules were observed with considerable rigour, both in the learned professions and in those which we now designate as trades. The formation of companies of tradesmen in England dates probably from the 12th century."

PRIDE IN TRAINING NEEDED

6. Again referring to Mr. Avey's well considered remarks, it is very true that we derive pleasure when we assist in educating the next generation. I recall a visit to a large middle western city. After the conclusion of business my host suggested a sightseeing trip in his car, and drove directly to a new and beautiful high school. That building represented to him the finest accomplishment of his city and was his chief pride. If we can achieve the same pride in the training of men for the salvation of our industry, we need have no fear of its future. This country's accomplishments in the field of general education for rich and poor alike, have placed it in advance of the whole world. In this one respect we can prove the results of the high standard of living which has resulted from our economic system under the protection of our Constitution. But what a frightful pity if we do not apply the same natural instincts and pride to the education of apprentices today who must be the future key men of industry.

ACTUAL TRAINING UP TO LOCAL ORGANIZATIONS

7. It is neither possible nor logical for a national organization to install apprenticeship in our widely differing shops. Each one of us has specific problems peculiar to our own location, class of work, and sources of labor. In April 1935 the American

Foundrymen's Association in conjunction with the National Founders Association issued the booklet entitled "Standards of Four-Year Foundry Apprenticeship", which may be adopted by all of us as a basis for a program. I now understand that the N.F.A. has assigned to the Penton Publishing Company the responsibility for a new and completely revamped edition of "Elementary Foundry Technology", which may well be used as a primary text book. Thus through the auspices of our national organizations we are provided with basic standards and printed material, in addition to constant stimulation through printed matter and discussions at meetings. Chapter organizations can very effectively give major prominence to local pressure for apprentice training.

Success Determined by Attitude of Executives

8. All of these activities are in the right direction, but are only supplementary. An adequate, even a safe number of skilled craftsmen, can be provided only if every executive, superintendent and foreman makes it his sworn duty to train men for his own future needs. Right here at this great convention of foundrymen are gathered those who will determine the success or failure of apprentice training. I have never believed in the principle of signing a pledge either for temperance or license. Voluntary commonsense is the better means to the end. If we cannot rely upon the commonsense of every foundryman to train men, it will be a sad commentary on the intelligence of the leaders in our industry.

Basic Necessities for a Successful Training Program

9. I have been asked to give a brief description of the apprentice plan in our company. While our plan is designed obviously to meet our own conditions, there may be features of it which will be equally successful if applied to other shops.

10. Before considering the details of the plan, let us consider some of the basic necessities of any successful scheme. I would list them as follows, in their order of importance:

(1) Hire boys who are best qualified by education, ambition and physique, to become skilled craftsmen. In this day and age this means a starting wage for apprentices at least equal to what we pay a laborer. Forget the old idea that an apprentice is an ignorant child. Hire an intelligent boy, treat him like a man, and pay him like a man. Please do not say that you cannot afford

to pay your mechanic of the future a good starting rate. It is just good business; the surest means of receiving a return on your investment; the only way to reduce the customary high labor turnover on apprentices.

(2) Do everything possible to sustain the boy's interest in his work. This may tax the ingenuity of his bosses, but there are many ways to do it. Give him a variety of work; let him inspect his castings; if possible take him to the machine shop to see what happens to his casting; try to relieve the drudgery within commonsense limits. Periodic increases in pay offer encouragement.

(3) Make provision for him to receive his practical training from those who are best qualified to teach him, whether it be foreman, molder, or special instructor.

(4) In the eagerness to train a molder, do not neglect the mental side of his training. You will need foremen and superintendents in the future, and every apprentice should be considered as a potential foundry executive.

FOUNDRY TRAINING PLAN

11. The apprentice plan in our foundries is simple and inexpensive. It is not recommended as an ideal plan. We hope that it will serve our purpose. It has been described previously on another occasion, but I have been asked to repeat it.

Rates of Apprentice Pay

12. For several years the company has had a four-year training period under the careful direction of the superintendent and his foremen. We had then, and still have, a starting rate of 40 cents per hour for foundry apprentices who must have at least a grammar school education. An older boy with high school education is started at 45 cents.

13. The new apprentice is promised a raise of 3 cents per hour every six months, if his work is satisfactory. On that basis his pay is increased 6 cents per annum or 24 cents in four years. However, his eighth or final raise is 5 cents per hour, so that at the end of his training period he receives 66 cents per hour. Some flexibility is considered necessary in order to reward extra merit or to penalize unsatisfactory progress. So the new boy is told that he may receive an occasional 5 cent raise instead of 3 cents, if he does exceptionally well. On the other hand, if his progress

is not up to standard the superintendent delays the raise which is due him, for a period of one month, and urges him to "buck up". At the end of that probationary month, he either gets the increase or gets through.

14. During the depression, for a period of three years, work was so scarce that we put on no new apprentices, but throughout these years every apprentice received all of his regular raises, and at a time when no other raises were being granted.

15. A conscientious effort was made to give the boys an interesting variety of work. At times, of course, this was impossible.

Essentials of Plan

16. The essence of that simple plan was liberal wages, frequent and assured increases in pay, and a sincere interest on the part of superintendent and foremen. During the thirteen years of its operation it has produced some of our best molders and coremakers and up to a certain point has been highly satisfactory.

17. This method of apprentice training is still in operation but has been supplemented by a much more intelligent recognition of future demands. For many years we had taken boys from grammar school and taught them how to use their hands, but did nothing for their minds. Obviously it was a lop-sided training, which gave little or no thought to the future need of intelligent foremen, superintendents, and foundry executives. It was as foolish as teaching a ball player how to throw and catch a ball, but never teaching him how to bat. We had developed a strong defense, but no offense and certainly no scoring punch.

Related Instruction

18. About a year ago it was realized that we had provided perhaps adequately for "hand-work" but very insufficiently for "head-work". Not being located in a large city, we have no access to a vocational school. From time to time classes had been arranged in mechanical drawing, but these were spasmodic. In short, instruction in related subjects had been neglected.

19. In determining upon an educational training, certain basic fundamentals were agreed upon. In the first place, it seemed advisable for the boys and the management to share the expense, since it was felt that the apprentice would take more interest in something for which he was paying. Secondly, in order to assure control of the classroom it was decided that classes would be held

during working hours and that the boys would receive their regular wages during that period. And finally, that in lieu of a vocational school, correspondence courses should be combined with supervision and instruction by a trained instructor.

Text Material

20. Arrangements were made with a nationally known correspondence school to offer courses to the boys at reduced rates. On the same principle as group insurance, by selling the courses to a large number of apprentices, the correspondence school can offer much lower prices than could be obtained by any individual.

21. The correspondence courses include the following subjects: shop economics, mathematics, reading of blueprints, mechanical drawing, English, and such Foundry subjects as molding, cupola practice, foundry equipment, casting, elementary metallurgy, and elementary chemistry. The boy pays for this course approximately one hundred and twenty-five dollars over a period of four years, in weekly payments which are deducted from his pay envelope. If at any time he should be discharged or wish to discontinue his studies, the payments cease at once. It is evident that the boy pays about sixty cents per week for his instruction and in the case of a beginner who earns forty cents per hour, this compares with earnings of sixteen dollars for a forty-hour week.

The Instructor for Related Material

22. The company pays for the services of an experienced vocational training instructor who is at the plant every Wednesday and Thursday. During the balance of the week he is doing similar work elsewhere in New England. All day Wednesday and on Thursday afternoon he is available for advice and guidance to the boys, and he reads their papers and keeps careful records of students' progress.

Classroom Work

23. The school meets every Thursday morning for three hours, from eight until eleven. The class is held in an adequate room where every boy has a desk, and with the instructor in charge. In contrast with the sixty cents per week paid by each boy to the correspondence school, the company pays the boys their regular wages, up to a top limit of sixty-four cents per hour, for the

three-hour period and also, as previously stated, pays the instructor.

24. During the classroom period the apprentices are not always covering the same subjects, but have an excellent chance to study and to ask questions. With the close follow-up by the instructor, backward boys are discovered and can be encouraged and given special attention.

25. Another popular feature of the classroom period is the occasional appearance of an executive of the company who may talk to the boys on subjects ranging from cost accounting to current economic conditions. This gives the officers of the company an opportunity to prove to the boys their great interest in their advancement. They are told frequently of the future need of mechanics and supervisors and are impressed with fine opportunities ahead of them.

Related Shop Practice

26. As a further means of sustaining their interest, the apprentices are transferred to other departments for brief periods. It is not the intention that they shall spend sufficient time in the pattern shop or machine shop to learn very much about those trades, but they will at least have an idea of what procedure and operations precede the arrival of the pattern in the foundry, and something about what happens to the castings after they leave the foundry. And they learn at first hand the effect of poor castings on machine shop costs.

27. According to the present schedule, each foundry apprentice will spend six weeks in the Engineering Department, four weeks in the Pattern Shop, eight weeks in the Machine Shop. Coremaker apprentices must work eight weeks on Dry Sand, and five weeks on Green Sand. The molders apprentices follow the same idea but with thirteen weeks in the Core Room. Occasionally, arrangements are made to take all of the apprentices to other factories where they may see our machinery, and their castings, in actual operation.

APPLICATION OF PLAN TO OTHER FOUNDRIES

28. The intent in asking me to describe this plan which is in operation in our company is the hope that it will be recognized as a very simple plan which can be introduced into any foundry

at low cost and regardless of the absence of vocational school facilities. Those of you who operate production shops may question the necessity of training men because of the simplicity of breaking in green men on machines. But I would like to challenge such a position on the grounds that every foundry, at least, will need intelligent supervisors. We feel that by supplementing the old manual training system with mental schooling, the average intelligence of the graduate apprentices must improve, and in due course there should result a supply of material for foremen and superintendents.

CONCLUSIONS

29. In conclusion, there is a most important fact to be emphasized. The installation of an adequate apprentice training plan is neither difficult nor expensive. The failure to provide a plan appears to combine a large measure of laziness with a considerable degree of stinginess.

30. In the field of national politics we gradually are becoming aware that the inertia of otherwise intelligent people has caused our Congressmen to disregard the silent majorities and heed only the shouts of the organized minorities. The same fateful inertia has drugged us into a complacent disregard of the loss of the very sinews of our industry.

31. If a small fraction of the energy we put into sales, production, and finance is applied to apprenticeship, the problem is solved. It must not be a haphazard program. It must emanate from the chief executive of each company in the form of definite orders and should be followed up as closely as the monthly statement. Superintendents and foremen must be as eager to obtain good apprentices as they are to get good castings. Otherwise there will be few good castings in the future.

(*Discussion Begins on Page* 315)

APPRENTICE TRAINING—II

Apprentice Plans for Detroit Industries

By H. W. Boulton,* Detroit, Mich.

Abstract

The author outlines the beginning of the apprentice training movement in Detroit. At the first meeting, there were five speakers, and excerpts from these talks are given and the main points brought out. The author shows that each of the speakers had a different viewpoint. The chairman of the meeting appointed a committee which gathered information on the supply of labor in Detroit and the author gives some of their findings including a plan of procedure for rectifying the labor shortage in that community. The result was a co-operative plan in which both industry and the Board of Education joined. Since last November, when the plan went into effect, over 800 boys have begun apprenticeships. The author lists the various trades for which apprenticeship is available and gives the numbers of apprentices now being trained under one of the three plans now in effect. These are the co-operative, extension and plant school plans. He closes with a discussion of the need for skilled help in the foundry industry in the Detroit area, analyzing figures on available labor to show how many apprentices should be trained to make up for the normal loss of 5 per cent per year.

1. Every employer at some time or other has thought about apprentice training, discussed it, played with it, and in some cases has actually done something about it. In a number of instances, however, the start has been made and then a "let George do it" attitude has been adopted with the usual attending result.

2. What must be done to insure a real constructive job of training is for every one to get behind a training program and play his part, because we have a very direct interest and part to play. If we leave it to a small group, we will get nowhere. The pocketbook strings are held by *management* and unless *management* gets back of apprentice training it is never going to work.

3. In about 20 minutes I will attempt to live over Detroit's

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Note: This is the second of three papers presented at a session on Apprentice Training at the 1936 Convention of A. F. A. in Detroit, Mich.

past year of experience in apprentice training. It will be interesting for you to see how this movement started in Detroit, the steps that were taken after the movement was started, and finally, the results obtained. The high points are all that time permits but they are interesting and will show a real earnest effort to do a constructive and lasting job by the employers in Detroit.

THE START OF THE MOVEMENT

4. In February 1935, about 35 men assembled at the Wilbur Wright High School in Detroit to discuss a problem in which they were all in accord, namely, that there was a shortage of skilled labor in Detroit and what to do about it. Five speakers were on the program. It was their job to analyze the various phases of the subject for the purpose of bringing out discussion and at least outlining a tentative plan, and then build that plan, as time went on, to a point where it became constructive and an actuality.

5. I would like to reiterate the high points of the short discussions by the five men at that meeting.

WHY EMPLOYERS SHOULD BE INTERESTED IN APPRENTICE TRAINING

6. The first subject was "Why Employers Should Be Interested in Apprentice Training." Here are three of the vital points which came up for discussion:

(1) "Good Mechanics Are Priceless." Each of us will appreciate that fact when we go back into our own plants and talk to our foreman and listen to what he has to say about George, who is a poor excuse for a mechanic, and John, who is a good mechanic, and how much John gets out in comparison to George. You may pay John more money, but he does twice as much work, therefore, he is cheaper in the long run. The foreman must give more supervision to this poor mechanic. I think we will all subscribe to the statement that "Good Mechanics Are Priceless."

(2) "To Develop Executive and Leadership Talent." A carefully conceived plan of training, properly carried out, assures future trained man power for any chosen division of work. This statement seems obvious enough to preclude further discussion.

(3) "It is Both a Community as well as a Plant Asset"

because it develops stability within the community as well as loyalty to the employer.

7. In considering "Why Should Employers Be Interested in Apprentice Training," and having been an apprentice instructor myself, I may say from experience that some of the things management does with respect to employee training are almost incomprehensible from a teacher viewpoint. He thinks they lack judgment and he may be right to a certain extent—but I believe that the average factory superintendent or manager is a far more experienced man than the average teacher, as far as the factory is concerned. The manager believes as much in training as the teacher. Then why can they not get together and be in accord on the subject?

WHY SHOULD CITY SCHOOLS BE INTERESTED IN APPRENTICE TRAINING

8. The second speaker discussed the subject "Why Should City Schools Be Interested in Apprentice Training?" This speaker was alluding primarily to the technical schools in the community because he was discussing trade training. If the school authorities have an interest in trade training, they might be able to stir up enough interest in the community to be able to place the boys. In other words, they are selling their product. It is good business. Then again, if we do not make use of these schools, we as manufacturers, are losing something because we are supporting these schools through taxation.

9. The schools are interested very definitely, and they have been for a long time. But I think it is a fact that the manufacturer has not been quite as interested as he might be. It is a co-operative game. One cannot play it alone—the two have to play it.

APPRENTICE TRAINING EFFORTS IN DETROIT IN PAST YEARS

10. The third speaker reviewed the past achievements in apprentice training in Detroit. He made such statements as "Training programs have been carried out in the past with marked success in a few instances," "that economic conditions have resulted in a curtailment of apprentice training," and "that there never was sufficient training in the City of Detroit."

11. Speaking of Detroit's problem and the way Detroit

tackled it, in the past it was apparent that a few had shouldered the burden. It was another instance of "Let George Do It." We have been stealing labor to supply our needs. Such practices are bad for the community as well as unfair to the management that attempted to do the more desirable job through training.

Present Shortage of Skilled Mechanics

12. The fourth speaker discussed "The Present Acute Shortage of Skilled Mechanics."

13. The first thing he did was to define a skilled mechanic as a man "who knows *why* as well as *how*." He knows the limitations of tools and machines with which he is working, and the materials he is handling. Is there a present acute shortage of skilled labor? If there is not, there is going to be. Unquestionably there is. This speaker then advanced some reasons for the shortage of skilled labor.

14. There has been little or no training in Detroit since 1930, and we have a normal loss in any trade of 5 per cent per year. This is a loss due to superannuation, death, leaving the city, changing occupations, etc. This is a normal loss. Then we have restricted immigration. We can rely no longer on the importation of trained mechanics. The speaker also referred to Detroit's picture of 66,000 skilled workmen. Now 5 per cent or the normal loss of 66,000 is 3,300 per year. Is Detroit's picture alarming? It is very definitely so. Why is it that such conditions exist? We are good managers, we operate our business well, we make a profit—we do now, at least, or we are attempting to—so there must be something wrong.

Planning to Secure Facts on Existing Condition

15. The last speaker's subject for discussion was "How Detroit Manufacturers and the Board of Education Can Correct This Situation." He stated that it can only be corrected through concerted and co-operative effort. A community program, if you please. The schools cannot do the job alone; they can give us pre-employment training but not full fledged artisans.

16. Here are five men who threw five different viewpoints on the table. The meeting was in an uproar immediately. It is a problem. How are we going to attack it?

17. To cut the argument short, the chairman of that par-

ticular meeting appointed a committee of nine men who were to gather the facts for presentation to management in an attempt to induce management to do something about it. It was a job very much like a young man who came to me when I was a foreman in the shop. He had been with me about 4 months when he requested a transfer to a lighter job. I was alert to remind him that when he hired out he asked for work. He said "yes, but if I asked you for a drink of water, would you turn the hose on me?" And that is what they did to us on this committee—they turned the hose on us. We had to go to work and it was a job.

NEED FOR ALL ROUND SKILLED MEN

18. I think the success of the work of that committee is shown in the results obtained to date. Permit me to read to you some excerpts from the report. "Despite the intensive development of our production facilities with 'one operation machines', there is still room, not alone for the specialist, but also for skilled workers who can turn their hands to any job they may be called upon to do."

19. This particular statement is an attempt to debunk the idea that our industries are so specialized that we have no need or necessity for an apprentice training program which has in it the features we like to look upon as training. It is true that the masses do not require an intensive training program but do not neglect the fact that the masses must be supervised and that the machine tools or equipment with which they work have to be maintained.

WHY THE SCARCITY OF SKILLED WORKMEN?

20. Under the heading of "Why the Scarcity of Skilled Workmen?", the report reads "the American youth is turning toward the white collar job. This is a commonly accepted theory, but this common explanation ignores all the facts. Actually, the scarcity of skilled workmen only reflects industry's failure to shoulder the responsibilities of an apprenticeship program."

21. We have a large number of intelligent young men, in the city today who are seeking an opportunity. The facts that I am going to give you later will bear that out. They want an opportunity to go out and learn something. Industry was not giving it to them, so they began to spread out and get the jobs

that they could get. It was not a question of selection on their part, it was a question of necessity.

22. Today, it is a much different proposition in Detroit. These young men are coming back to us. We cannot take care of them all, but they are coming back because they see a well prescribed training program that is fundamentally sound, that will give them a living as well as a chance to learn something to get a living in the future years. I think that is true of every young man who has come to us to apply for an apprenticeship.

CAN INDUSTRY AFFORD NOT TO TRAIN APPRENTICES

23. The real question is, can any industry in Detroit afford not to train apprentices rather than, can they afford to train them? I will make this statement—any apprentice program properly supervised and conducted will not cost any company a nickel. That statement was made by my superior when I happened to be an apprentice supervisor. Hundreds of inquiries came in asking as to why that statement was made and could it be proved. Well, it could not be proved on the spur of the moment but it eventually was. Accurate costs of the training program were kept and it did not cost a nickel. It can be done and is being done in every properly conducted training program. I do not mean that you make money 10 years from now with the boys you are training. You make it right on the job during the training period in a good many ways.

GOVERNMENT FIGURES ON EMPLOYMENT IN DETROIT

24. Here are some Government figures pertaining to the gainfully employed in Detroit:

(1) Of all the gainfully employed in Detroit, 48.5 per cent are in the manufacturing and mechanical industry.

(2) In other trades, such as stores and sales, and so forth, it is 13.9 per cent.

(3) In clerical, it is 11.3 per cent.

(4) In domestic and personal services, 10.4 per cent.

(5) In transportation, 6.9 per cent.

(6) In professional, 6.2 per cent.

25. Contrast the opportunities for young men in Detroit, 6.2 per cent in the professional fields, and 48.5 per cent in the

manufacturing and mechanical industries. That is a very significant fact.

26. The entire survey was conducted with only one thought in mind, constructive service to Detroit manufacturers. Earlier in this discussion I stated that there were 66,000 skilled workers in Detroit. The following is a breakdown according to trades:

Machinists	28,577
Tool and Die	16,060
Electrical	6,975
Forging	3,600
Welders	2,676
Sheet Metal Workers	2,579
Millwrights	2,361
Pattern Makers	1,621
Molders and Founders	1,400
Wood Workers	805

SOURCES OF APPRENTICE MATERIAL

27. Concerning the source of apprentice material and where are we going to get these men, the report reads: "Startling facts came in rapid succession when the committee began its investigation in Detroit. One of the most significant was the rate at which the boys drop from school when the law ceases to compel their attendance." That is very startling. "Normally about two-thirds of Detroit boys entering the public school system leave before they are graduated from high school. Only one-third finish."

28. Of course, many of these young men are forced to go out and go to work and they are picked up on these so-called specialized operations where we can teach them a job in a very few minutes, hours or days, and we are glad to get them—but, as I said before, who is going to supervise these men, and who is going to maintain the equipment on which they work?

PLAN OF PROCEDURE IN DETERMINING NUMBER TO TRAIN AND SECURING SUPERVISION

29. Here is a suggested plan of procedure, as this report indicates: First—"Determine what departments in your plant can use apprentices and how many." In other words, do not go into training with the idea that it is a panacea for the curing of all your ills. Do not over-man your plant with apprentices because

that will work a hardship and will be detrimental to the morale of the department.

30. Second—"Appoint some individual who is in sympathy with the training idea as a supervisor. Make him responsible for co-ordinating the plan and carrying out the schedule." You cannot leave supervision of training to your foreman. You might do this in a small shop but I think that even there it is questionable. Get someone on the job who knows how to handle boys, who is in sympathy with boys, who is a good mechanic, and who has some teacher instinct and make him responsible for the training program. If you do not do that, any training program will fall of its own weight. I have witnessed such failures. The boy goes out into the shop, the foreman is busy, he neglects the boy and the boy is set to sweeping the floor or running errands. How can you expect to hold a boy's interest in that type of work? He can go out and get that type of job anywhere. He is there to specifically learn something. He certainly is not learning anything by using a broom.

31. I know the old apprenticeship. The first job was to sweep the floor. The new apprentice was called in, then in a ceremony with apprentices around him, he was handed a broom and told that was his job until another apprentice was hired. They hired them on this basis. "We will give him a broom because he will not bother us much and we will see if he can take it." You can bet your bottom dollar that the average American boy can take it. You do not have to go out and try to prove it. You can prove that within your course rather than giving him such a probation period which is a slap at his pride rather than his ability.

Definite Schedule of Training Necessary

32. "Third—lay out a schedule of work to be mastered by each apprentice." In my humble opinion these spasmodic apprentice programs are bad. If the boy cannot see something constructive ahead, that he is going ahead step by step and climbing a ladder, it is only a short time before his interest begins to lag and then we are apt to condemn him as being shiftless.

33. "Fourth—Call the committee for further information or for any assistance necessary in organizing this plan." This committee stands on record in Detroit as being willing to give any manufacturer all the assistance it can possibly give him at any time in furtherance of an apprentice program within his plant.

34. The foregoing excerpts from the report serve to familiarize you with the thoroughness of the research by the committee.

RESULTS OF APPOINTMENT OF APPRENTICE DIRECTOR

35. The first thing accomplished was to appoint an apprentice director. The Employers' Association of Detroit appointed this man and put him on their payroll. Briefly, he is the contact man who goes around selling training to those employers who are not already in line, assisting them in organizing a program, getting forms together, getting the instruction material and all such things that might be necessary. In other words, he will take over the job, if they so desire, to get the program functioning on a practical basis.

36. The second accomplishment under the direction of this director is that more than 800 boys have been put to work on approved training programs since the start of this movement last November. There are many more boys in the City of Detroit who are on apprentice programs of the spasmodic type. Eventually, we hope they will come under the banner of the approved training type.

37. We have 81 firms listed as definitely training apprentices. There are 28 firms that have six or more. There are 12 skilled trades lined up to date. Some of those trades are:

Machinists	Automotive Service (Garage Man)
Tool and Die Makers	Electricians
Model Builders	Machine Maintenance
Drafting	Pattern Makers
Designing	Foundrymen

Apprentice training has spread out to include junior accounting and clerical work. One concern in the city is running quite a fine program on junior accounting work.

THREE TYPES OF PROGRAMS IN DETROIT

38. There are three types of programs in operation in Detroit.

Co-operative Plan

39. One we call the co-operative plan, with which probably you are all familiar. The boy alternates with half his time in school and half his time working. At present, there are 265 boys on the co-operative plan, that is, co-operating with the Board of Education.

Extension Plan

40. The extension plan is where the boy is hired full time and goes to school four hours or more a week on company time. There are 153 boys participating in this type of training.

Plant Schools

41. There are plant schools in the city where the industries are large enough to maintain their own school. There are 265 boys enrolled in such types of training. I think this is a very excellent start in this city.

THE FOUNDRY IN THE DETROIT PLAN

42. The Detroit industries have taken the right step. What is the foundry industry doing in Detroit? We have 1400 molders in this city today. On the basis of 5 per cent normal loss, we should graduate 70 boys each year to keep up our quota, or we should have 280 in training at all times. We have less than 100. If any of you gentlemen are from Detroit, I hope you will see this picture and see what you can do in getting more boys into molding on the basis of apprentice training.

43. We have 1,600 pattern makers in Detroit. On the basis of a 5 per cent normal loss, we should graduate 80 each year, or have 320 in training at all times. There again we have less than 100 in training. In Detroit, we have a shortage of this type of labor—a very definite shortage. It is true that the foundry is highly mechanized but the business is there and it must be supervised, the equipment must be maintained the same as in other manufacturing industries.

44. An effort has been made to give briefly and sketchily what our problem was in Detroit and how we have attempted to solve it. It has raised a great deal of interest in this city and we are getting excellent co-operation from the manufacturers. I was talking to the Director of Apprentice Training and he told me that to date only one company that he has approached turned him down.

45. Let me close with these remarks, I think Detroit has made a step forward. I hope that the step will be continued and that the country at large, in the manufacturing centers, will look to apprentice training as we have in Detroit and make the same progressive, forward step.

(*Discussion Begins on Page* 315)

Training Foundry Apprentices in Cleveland

By James G. Goldie,* Cleveland, O.

Abstract

In this paper, the author outlines the program used in Cleveland to train apprentices in foundry practice. The fore part of the paper deals with the events that lead up to the establishment of the program and a description of the facilities available at the Cleveland Trade School for the training of foundry apprentices. The author then takes up in detail the entrance requirements, length of the course, course of study and instruction, methods of instruction, placement of apprentices and rates of pay. The method used in Cleveland is co-operative.

1. To give a true picture of the Cleveland system for training foundry apprentices, we must go back to the Fall of 1928 and the Spring of 1929. In those years, the scarcity of good molders was not so great perhaps as it is to-day, nevertheless, the scarcity of young men coming into the trade as apprentices was as great, if not greater, than it is to-day. To the foundry group of Cleveland, this stood out as a real problem, a problem which, if not met and challenged, would reap a bitter harvest as far as the foundry industry was concerned.

2. A special apprenticeship committee was formed for the purpose of enquiring into the different methods and plans of apprentice training. Luckily for this committee, they were not required to go far afield to find a plan because right in the heart of the city was the Cleveland Trade School. A visit to this school brought out the facts that apprentices were being trained for all the building trades and a large machine shop class but nothing being done about foundry work, not even a place in the school where a foundry could be started.

3. This committee were so enthused with the method of training apprentices at this school that they decided to enquire further into the matter with the result that at the next foundry meeting, representatives of the Cleveland Board of Education and the

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Note: This is the third of three papers presented at a session on Apprentice Training at the 1936 Convention of A. F. A. in Detroit, Mich.

Cleveland Trade School were invited to attend and put before the group the requirements and the plan for foundry apprenticeship training which might be carried on at the school.

4. The plan was briefly this. The Board of Education were willing to build an addition to the school on the vacant lot adjacent to the school, this addition to comprise the main foundry, core-room, cleaning room and large study room. They would also pay the salary of the instructor and, as far as possible, supply the essential yearly supplies to keep the department going and when possible purchase equipment needed for instruction.

5. In return for this, the foundry group had, first, to equip the newly built foundry with the necessary equipment and supplies to carry on instruction. Secondly, they had to set up a committee which would meet frequently with the school officials and instructor to set up the course of study, revising the course content at least once a year, adding to, or taking away, as the foundrymen saw fit. This meant that the teaching content and methods would be determined by the men who knew what they wanted the apprentices to know. Thirdly, the foundries had to determine the number of apprentices that should be enrolled each year, this number to be based on the approximate number of placements that could be made. Needless to say the foundrymen accepted the plan and by June 1929 the building was completed at a cost of $50,000.

6. The Apprentice Committee had been busy all during the winter raising money and securing donations of equipment so that by the time July 1929 came around they had sufficient to equip the foundry in the most up-to-date fashion. The supply houses were also very good, some going as far as pledging supplies as long as they were in business.

7. It might be well at this time to give you a picture of this school foundry. The main foundry is 65 ft. long by 30 ft. wide with a balcony all the way around. It is equipped with a 2-ton electric crane, 27-in. cupola, brass furnace and an aluminum furnace, a sand mixing mill, six molding machines of various types, stations for bench molding, snap and slip flasks of various types and sizes and floor flasks in sizes from 24 in. square to 96 in. square.

8. The core-room is a separate room off to one side of the foundry and in it is everything that might be found in any com-

mercial foundry. A large gas fired core oven and stations for four core makers. The cleaning room is off the hall which leads to the foundry and in it we have what we feel is the most modern equipment, sand blast mill, cabinet, tumblers and grinders with full exhaust system, also air chippers and grinders.

9. The study room is across the hall from the cleaning room and this is more like a foundry laboratory where one can find all kinds of material and specimens of foundry work which are used in the teaching of foundry theory.

10. Such is the place where the foundry apprentices of Cleveland are trained. A real foundry with real equipment and the atmosphere of the typical foundry. The apprentices are dressed for the part in over-alls and work shirts and the instructor dressed likewise, ready to instruct his charges on the dirtiest job.

Entrance Requirements

11. A great deal of publicity had to be given to the foundry school during the months prior to the opening. This was done through the local newspapers, visitations to all the High Schools in town, and posters in all the foundries; in other words we had to sell foundry apprenticeship to the eligible young lads in the community. This proved very successful because we opened with 25 apprentices. To enter, a boy must be 16 years of age, have finished at least one year in high school, pass a physical examination and be of average height and weight. He must bring with him a record of his work and grades from his previous school and be recommended by his former teacher and principal. Upon applying at the school, the boy is interviewed by five different instructors who rate the boy according to a system set up in the school. The boy's social and economic background is checked and he is then given a series of tests to determine his shop possibilities.

12. From all this we determine just whether a boy should be allowed to enter or not; our batting average is not 100 per cent but it is very favorable. Should we slip up and allow a boy to enter who is not capable of making the grade, this is usually found out before the end of the first 6 weeks' period and always before the end of the first semester. Should this be the case, a transfer is arranged and the boy guided into something else which might be more suitable, so you see entrance requirements are rather selective.

Length of the Course

13. The course is set up to cover a period of four full years. The first year the boy spends full time in school. Second year he spends two weeks in school and two weeks in the foundry where he has been placed (being paid during the weeks he is in industry). Third year he attends school one day per week and works in the foundry four or five days, on whatever the foundry is doing, being paid his regular rate by the foundry for attending school. Fourth year the apprentice attends school half a day per week and works in the foundry the remainder, again being paid for this half-day.

Course of Study

14. The course, as stated, is set up to cover a period of 4 years on a co-operative plan. During the apprentice's first year in the school, his time is about equally divided between actual foundry work and related theory and subjects directly related to the foundry. By related theory, I mean the whys and wherefores for doing certain jobs. For instance, when teaching a boy to temper sand, he is given instruction on the selection of the sand, the care of the sand, and the requirements of the sand, and so forth. Also, under the same rule when teaching him how to ram a mold, he is given instructions on the requirements of this mold, the theory of venting, the action of the molten metal inside the mold. In core-making it is the same. He is not only instructed how to make cores but he is given the reasons for doing everything he is instructed to do. In cupola practice, the same holds true. In the re-lining of a melting zone, he is not only trained how to daub up but he is made familiar with the conditions which prevail in that part of the cupola during the melting operation. This related theory is not taught as a separate subject but on the job, during the performing of the actual work. Some parts of it are taught (out of necessity) before the job starts—but never after the job is completed. Revision or re-teaching is always necessary and that is done after the job is completed.

15. By way of illustration, suppose we have two boys working on the floor on a job which involves the setting of cores. These cores require chaplets to hold them in position. Up until this time these boys have set cores, but always on jobs which did not require chaplets. This is a new experience for them, so now

is the time to acquaint them as to the reasons for using chaplets. Not only the two boys on the job but the whole class is summoned to the spot where the mold is, that they may hear and see the actual demonstration. At other times, the whole class might be required to leave the foundry and report in the study room where a blackboard demonstration might be necessary to put across a certain phase of the theory.

Method of Instruction

16. One might ask the question at this time, how do you put across all this information and instruction and feel half-way sure the boys are getting it? On every job to which the boy is assigned, he is given, first, an information sheet which contains all the necessary information about this job he is about to do. Second, he is given an instruction sheet with definite instructions what to do, and how to do them. When he arrives at the point where is is stopped for reason of not knowing how to do the next operation, that is where the demonstration by the instructor takes place that has just been mentioned. While being given the oral explanation of the theory, he also receives a written copy of the theory which he keeps for future reference. These sheets are all made out by the instructor in charge. We do not follow any textbook, although we have a very complete library of all the books on foundry practice, trade publications and printed material put out by the supply houses. By means of home work and written assignments, the boys are taught how to use these books as reference material in the solving of foundry problems.

17. During the first year the boys are given practical instruction on bench-molding, floor molding, machine molding, core-making, cupola practice and cleaning room. The class starts out as a whole but after the first month, it is divided into groups, these groups rotating to the different departments every week. At the end of the first semester or 13 week period, you have a class which is familiar with the fundamental processes of all the branches of the trade. This continues during the next semester and at the end of this period, the boy is ready to go out to a foundry.

18. I would like to make it clear at this time that we do not claim to turn out finished molders from the school because this is impossible in a school, but what we do claim to do is that after this first year we recommend to the foundries boys who have

proven their interest, ability and aptitude for the foundry trade; furthermore, they know the foundry language; they know what the molder is doing and why he is doing it when he sees him on a job and if put to working with this molder he knows what to look for when told to get certain things. In other words, the molder loses no time following the boy around to see that he knows what he is looking for. Of course, in many cases we have boys who go out and after the first week or two are put to work by themselves on a bench or side floor and in other cases boys have gone out and right away are on their own. This condition, of course, depends on the type of foundry in which the boy is placed.

19. I said that during the second year the boy spends two weeks in the foundry and two weeks in the school. During his weeks in the commercial foundry, he is under the care of a supervisor whose job it is to instruct the apprentice on any new phase of the work and to see that this boy is not kept on any one job longer than necessary. The instructor from the school also makes periodic visits to ascertain what type of instruction the boy should receive when he returns to school for his two-week period. During the two weeks in school, he receives instruction on more difficult jobs, more advance theory and blue print reading and mathematics.

20. The third year he works five days and returns to school for one day, for blue print reading, mathematics and metallurgy. The fourth year for half-a-day per week, finishing up his course.

21. I spoke of related subjects. By related subjects I mean subjects directly related to foundry work, pattern-making, sketching, blue print reading, mathematics and English. The foundry boys spend three hours each at pattern-making and blue print reading. The instruction for this being given by a real pattern-maker who has been out in the foundries and knows just what these boys will use when they get out into industry. By the same token, the boys in the pattern class spend one full day in the foundry. Mathematics and English are taught not just as commercial subjects but as foundry mathematics and industrial English, taught by the foundry instructor.

Placement of Boys

22. Placement during the depression wasn't so easy. Nevertheless, we managed to place quite a few on the co-operative basis.

For the boys that we did not place, we had a plan whereby they could stay on at school and finish their school work and when the time came they would go out full time. That time did come and when the call came for apprentices, we had boys ready to go out. The placement situation today gives us no concern because the shoe is on the other foot. The fact of the matter is, we have more foundries wanting boys than we have boys ready to go out, so it's a case of the foundries putting their name on the waiting list.

Rate of Pay

23. After placement, these boys and the foundry are signed to an indenture contract. The rate of pay is set up by the committee with specified increases stated, provided the boy's work in the foundry and at school is of a satisfactory nature. At present, the starting rate is 35 cents per hour rising to 75 cents during the last three months of the four-year period.

24. Before concluding, I might say that at the school we pour gray iron once a week and the non-ferrous metals every day in the week. The jobs we work on are all for use. We don't pour just for the sake of pouring and then melt the castings over again. This is a big factor in school training. The key-note of training apprentices in a school is to have the school set up a program decided upon by industry then put that program to work in as near actual commercial conditions as it is possible to set up in a school, and last but not least, have a foundryman teach it who knows what it is to work in a foundry.

25. In closing we wish to give a word of praise to the different groups who combine their efforts to make the Cleveland Plan the success it is, the Associated Industries of Cleveland, the Foundry Group of this Association, The Foundry Apprentice Committee and the Board of Education of the City of Cleveland. Co-operation is essential and we are happy to say we have it in Cleveland.

(*Discussion Begins on Page* 315)

APPRENTICE TRAINING

DISCUSSION

CHAIRMAN S. WELLS UTLEY[1]: Industry in America today finds itself in a rather peculiar and somewhat embarrassing position. With recovery in the heavy goods industries, including most of the foundries, to a position where they are operating at about a 50 to 60 per cent level compared with maximum production of 1928 or 1929, most lines of industry are reporting a definite and serious shortage of skilled labor. At the same time that this shortage is reported, we are told that there is unemployment in this country amounting to somewhere between 8 and 12 million people, depending upon whose estimate is taken. Nine million people out of employment and yet the foundries, machine shops, tool shops, etc., cannot find the kind of men they want to employ. That is true not only in our industry, but is true of every industry with which I have come into contact.

Today a foundryman from Los Angeles told me that in his district not only were they unable to get pattern makers, molders and core makers, but the employment agencies had told him every single concern in Southern California who used machinists were listed with them as wanting to get more machinists. A contractor refused to do a painting job for him because he said he could not get any painters.

That is a queer picture. There must be some definite reason for it. It is quite evident that for some reason or other we have not, in the past years, been training men to do the skilled jobs in industry.

Perhaps one of these reasons is that American industry has been built quite largely upon the skill of men who came from other countries. We depended on the Scotchman, Englishman, Scandinavian and German quite largely to furnish us the high degree of skill we needed to build up the American industrial product. Another reason perhaps is a lack of interest, so long as there was this reservoir of skilled labor, on the part of those who were responsible for the management of industry.

And a third one, I am very sure, has been due to a mistaken social policy in this country. We all know that one of the fetishes of organized labor has been the desire to create a shortage in craft trades by discouraging apprenticeship. That is nothing new. If you will read the story of the Guilds of the Middle Ages, you will find one reason they failed was because the workmen of those days had the same attitude and refused to pass on to the younger fellows the skill which they had accumulated.

The way that principle has expressed itself has not been in the control of shop conditions. It has been through the adoption in the states of so-called child labor amendments which describe a child as anybody under 18 years of age.

I do not believe any of us will take any exception to the desirability of prohibiting the labor of young children in any kind of organized industry. Some of us, however, when we go to our respective alma maters and see the freshmen football team, or a freshman crew racing, or when

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we go to our high school and preparatory school games and realize that a large number of those boys playing football and racing in the crews are under 18 years of age, have some question as to whether those men are still too young to work.

When we face the situation that in this country there are nine states in which it is legal for a boy to marry at the age of 14; there are two or three others in which he can marry at the age of 15; there are others in which he can marry at 16 and 17, so that in 25 states of the Union a man can be married and have a child or more of from 1 to 3 years of age before he becomes old enough legally to go to work under the laws of that state, we have reduced the situation to absurdity.

As you gentlemen know, most state laws provide that a boy cannot go to work in a hazardous occupation under 18 years of age, even though he can go to work at 16 years of age under certain conditions. It has worked out so that the jury has the determination of whether the particular job is hazardous or not. Most of us in industry know from practical experience how a jury looks upon these cases. The result is that it is practically impossible, excepting under very exceptional conditions and with special arrangements, to employ boys in a shop where they may possibly be hurt. Of course, they may be hurt crossing the street, but that does not make any difference. The public is responsible for that, while industry is responsible for the other.

When he is 18 years of age, the boy has arrived at a place where he no longer wants to become an apprentice and learn a trade. Rather he wants to become a workman and earn as much as he can. At 18, a boy usually prefers to go on a drill press or something else, and earn as much as he can rather than learn some trade whereby he would be of a greater benefit to society, to industry, and to himself when he arrives at that period of life when he does not have the strength and agility of youth.

In addition, we have taken the attitude that every boy should go to school and learn from books until he is 18 years of age. The fact is, there are a lot of boys who do not naturally learn from books and to whom book learning up to 18 years of age is not only a hardship but a good deal of a curse. These boys would actually be much better off if they went into a shop and learned to do something with their hands rather than to sit in a school room and try to absorb something from books.

Because of this situation, we have been throwing a lot of the young fellows into what we call "white collar" jobs and we have not been teaching them to take their place in industry.

There are some interesting figures that have just come out comparing the census of 1910 with the census of 1930, showing how thoroughly this has worked. In 1910 the census shows the number employed in the transportation industry was 2 million 600 thousand. In 1930 that figure was 3 million 800 thousand, an increase of 45 per cent.

When we come to those who have gone into merchandising, store keeping, selling, and careers of that kind, the figure went from 3 million 600 thousand to 6 million, an increase of 68 per cent. Those who went into professional services increased from 1 million 600 thousand to 3 million 200 thousand, an increase of 92 per cent. Those who went into domestic

and personal service increased from 3 million 700 thousand to 4 million 900 thousand, an increase of 31 per cent, clerical service, 1 million 700 thousand to 4 million 25 thousand, an increase of 131 per cent; those who went into public service, from 459 thousand to 846 thousand, an increase of 86 per cent.

You can see how this bears out what I have said that during these last 20 years we have been graduating our young fellows into "white collar" jobs instead of graduating them into skilled jobs in our own shops. Because of that, a large number of the people, who might otherwise be healthfully employed today, are now on the unemployed list. When you think of these 9 million 600 thousand who are unemployed, you must remember that the unemployment in industry today, in the manufacturing and mechanical industries, is only 1 million 200 thousand, and that the remaining 8 million 800 thousand people who are unemployed have never been engaged in manufacturing or kindred industries. They have all come from other lines, of which these I have cited are typical, although they are not all-inclusive.

The job, then, of industry is to get the interest of more boys back to the skilled branches of industry, so that some of the boys who are now going through school, and are going into these other lines of work, lines which are attractive at first, but which are not so productive or so sound when it comes to such storms as we have recently had, will be attracted to our industry.

DR. C. B. CONNELLEY[2]: I would like to ask Mr. Goldie if his Cleveland school is getting any funds from the Federal Government under the Smith-Hughes Act?

MR. GOLDIE: Yes, this apprentice system is open to all communities in the 48 states of the Union. The Smith-Hughes Act was passed in 1917. Since that time there have been a few more acts passed whereby city boards can secure so much money for every hour a pupil from industry comes into the school building. In Ohio, the School Board also receives an appropriation from the State for every hour these boys put in at school, proportionately.

DEAN CONNELLEY: We worked 10 years to get the Smith-Hughes Bill through before it became an Act. When it was passed, it had been changed in such a way that it is more academic than it is industrial, and that is indicative of the trouble with this country. Most people look at trade training as something inferior. I believe there is just as much respect and dignity in a pair of overalls worn by a man of character as there is in a silk gown in the pulpit.

C. J. FREUND[3]: May I repeat a comparison with reference to training which was made very forcibly by Dr. Wickenden of Case School before the Society for the Promotion of Engineering Education. He showed that the power and communication utilities in the United States, regardless of economic conditions, have been uniformly prosperous, have always made good money. Most other industries have been only spasmodically successful.

On the other hand, he showed how these utilities and these utilities

[2] Carnegie Institute of Technology, Pittsburgh, Pa.
[3] Dean of Engineering, University of Detroit, Detroit, Mich.

only, of all industries, have systematically selected and trained their men over the years.

It is hard to prove that there is a connection, but it seems to me sensible to assume that there is a direct connection between the fact that the communication and the power utilities have carefully selected and trained men, and the fact that they have been uniformly successful.

Now, what does such careful selection and training of men mean? It means that every man in every position throughout these organizations is an expert. He knows his job thoroughly and he does it well. We need to make no complex surveys or researches to show that such a state of affairs will inevitably reveal itself in the economic status of that business.

The railroads also are a utility and they have not consistently made money. Neither have the railroads consistently done a good job in the selecting and training of men.

I am now in a position to talk objectively about all this. Employers of all types have come to our college looking for young graduates. The ordinary employer comes in and says he wants to talk to a few boys. We send for a few boys, give him an office, and send the boys to him. The ordinary employer gives the boy a cigarette, asks him a few questions, says he is a nice boy and asks us if he does well. We say, "Yes, he does well—he's a fine lad, a nice lad."

"Well, maybe we will give him a break."

On the other hand what do the utilities do? They come in with a regular, set procedure to find out every pertinent fact about the boy, what courses he has studied, in what activities he has taken part, what contacts he has made, whom he has known. They get a complete picture. And their training procedure, I know, is just as thorough as that.

I should suggest that the foundry business, which is trying hard to get back on its feet and to make some money adopt some procedure for strengthening its man power, and I do not see how you can do it any better than by apprenticeship training. There is no other solution. If you want to train men systematically, you have to teach them the things they need to know, and what they need to know is your trade plus some business facts, and apprenticeship is the way to do it.

Someone has said that our A.F.A. Apprenticeship Committee has been doing a labor of love for 20 years; he did not say, but maybe thought, that we have nothing to show for it. And I suppose you will say we are merely telling an old story over again. The Committee pleads with the foundryman to save himself. The industry needs trained men and apprenticeship is the best training method. The Committee has the necessary information to get apprenticeship under way; we have many reports and papers. All you have to do is to follow the directions and you can get the right young men into the shops and give new life to the foundry industry.

CHAIRMAN UTLEY: I do not believe Dr. Wickenden was altogether right in his inference that the public utilities had gone on showing earnings during the depression because of the very fine type of men they built up in the apprentice systems. If they have done that, they are entitled to credit and they are getting wonderful organizations from it.

But that is not the reason, in my judgment, why they have been able to show these same results during the depression.

The power companies made that money because they devised in the early days a method of selling their products that is way above what anybody else has been able to do, and they did it because of certain inherent factors in that business. If you and I, as foundrymen, were able to charge our customers a "demand charge" on one hand and then a "service charge" for the casting we send out, so that when we did not have anything on the floors in the foundry, the customers would still be paying us for keeping that floor going, paying for the overhead and machinery and upkeep, we would make money during depressions, too, and that is the reason the power companies have made money.

I am not objecting to that. I think there are a lot of logical arguments for it. But I am saying in my judgment that is the reason they have solved this economic question rather than because they had gone into apprenticeship training. I think we should recognize that and not kid ourselves into thinking that if we do the same thing with apprenticeship training, we are going to get the same economic results at a time when we have to carry the burden of the empty floors rather than having our regular customers do it.

ROBERT GREGG[4]: One time in San Francisco, I was asked to take a number of students from one of the colleges through the foundry, which I did. The next day the professor gave them sort of a questionnaire asking them what they thought of the foundry industry for a livelihood. The boys wrote out several answers. One chap wrote: "In the first place, the work is dirty; in the second place, it is hard work; and, in the third place, you have to know too much for the little you get out of it."

Today I have been driving through the country and have seen a lot of foundries. I have been asking them what wages they pay in the different shops, and I surely was surprised. I thought we paid lower wages in Los Angeles than any place in the country, but I find we are paying above the average.

Several times in Los Angeles I have asked foundry owners who have sons old enough to become molders, whether they were learning the trade, and not a single foundry owner has a son learning the trade. I heard one foundry man say, "No, no; I would sooner have my boy do anything than learn the molder's trade." They believe the molder's trade is beneath them, and want some other man's son to do the dirty and hard work.

Now, as to pay, longshoremen, taxi drivers, and those in other lines of work requiring no skill whatever and no hard work, will, on the Pacific Coast, get from 90c to $1.10 an hour, and they do not have to know anything. It does not take a strong back nowadays to be a longshoreman, while a foundryman has to have a strong back and he has to have some brains to be a successful molder.

I think the only way we are ever going to get our trade up is to lift it up from the bottom; pay our apprentices decent wages; give the man enough so he can clothe and keep himself; because when a man gets up to 18 years of age, he feels he ought to go out and paddle his own canoe from then on.

[4] Supt. Foundry Dept., Reliance Regulator Corp., Alhambra, Calif.

As Mr. Goldie says: "In the old country if your father worked in a foundry, you worked in a foundry. My father was a molder, and his father was a molder. They were always talking 'foundry—foundry'."

But the foundry industry today, as all foundrymen know, is not in the hands of foundrymen. During the depression many of the foundries got into the hands of other than foundrymen. These people are not interested in the foundry industry as a whole. They are attorneys, doctors, bankers, etc., in it just for, as you might say, a racket, for what money they can get out of it. They are not in it to produce something. In the old days, the molders took a lot of pride in their work, but the industry has gotten into the hands of manufacturers who were not brought up as apprentices and mechanics. I think the foundry owners themselves ought to put their boys to learning the trade, and then they would have a better idea of what the molders are up against.

V. J. HYDAR[5]: Mr. Chairman, it was rather refreshing to hear from the last speaker that he was told by somebody who was not in the foundry industry that you not only had to be too strong and eat too much dirt, but you also had to know too much for what you got. The usual impression, at least as far as I have been able to find out, is that all you need in the foundry is a strong back and a weak mind.

However, there is one point which I think could stand some stressing and which was not mentioned in any of these discussions. That is that apprenticeship, regardless of in what trade it is or in what department, affords the employer an excellent opportunity to build up a nucleus of skilled people who are worth money to him not only because of their technical ability, but because of the principles of citizenship and the understanding of economics and of the employer's problem that the employer can give them through proper related instructions. The related instructions should include, of course, the various subjects that we all commonly think of, but among other things, a fair background in the economic side of the picture. I think also that a good understanding of the employer's problem from the financial and the operating side of the business as well as the personnel side can be worked in.

The schools can help a lot in supplying the right kind of boys so that your selection need not be narrowed down to too close limits. The schools should be able to supply boys who are instructed not only along the technical lines, or along those academic lines which are more or less directly related to the mechanical trades, but also boys who have been given the right start in their attitudes toward their prospective employment. We, in Milwaukee, are enjoying a considerable amount of cooperation, not only from the Vocational Board but from the Regular Board of Education in the proper guidance of the boys coming through high school. This has been accomplished very largely through pressure that was brought on the schools by the people in industry.

Despite this fact, we still have numerous instances of boys coming to us asking for mechanical trades, of one kind or another, but without the proper academic background and with no logical basis for their selection of an occupation. When we begin to investigate their high school cur-

[5] Personnel Manager, Falk Corp., Milwaukee, Wis.

ricula, we find that they have had commercial courses, English courses, classical courses or elective programs which have included not a minute of algebra, no chemistry, no physics and never a hint of mechanical drawing or shop courses of any kind. In short, they have had none of the things that serve to build up a background so the boy can get started not only on the right foot but a few jumps ahead of the other fellow in mechanical work.

A good share of this is not because the boy did not have the proper inclination in the first place, but rather because the teacher who was appointed as his guide and advisor was woefully unfit for the task.

I am not belittling the value of the cultural side of schooling. It is highly desirable and beneficial, but should not be emphasized to the detriment of the bread-winning abilities of the recipient. The only person who can capitalize on his knowledge of Chaucer or Shakespeare is the teacher of English and he is no fit person to advise an aspiring mechanic.

High school teachers for the biggest part are still too prone to think in the terms of college entrance requirements only, and too frequently forget that the boy who is going into the factory and is going to put on overalls to earn his living needs to have some of the more homely sciences and some of the more homely facts taught him.

A. E. HAGEBOECK[6]: I cannot leave this meeting without disagreeing with Mr. Gregg. I have two sons, both going to college, and every summer these boys work in the foundry as any other apprentice boys.

John Ploehn, chairman of our Apprenticeship Committee, has a son whom I happen to know, worked all last summer in one of our large foundries in the cupola department. Another point that always gets a rise out of me is, when I hear a foundryman take the position that the foundry offers little or no opportunity for a high school or college graduate. In my opinion, there is no department in industry that offers greater return for our young men coming out of college, men who have brains and who are willing to work.

DEAN CONNELLEY: Following what Mr. Hageboeck has said, I would like to say this. At Carnegie Institute we have a scholarship fund organized by the Master Plumbers of the United States. That fund reaches about $140,000. We take two boys in Tech each year, sons of master plumbers, who are admitted by competitive examination. One stipulation is that these boys, who are taking this course leading up to sanitary engineering, must work three months each year for three years in the plumbing industry carrying the bag. Those in the school in charge of these young men say they do not need shop experience to become engineers. They maintain they are leading up to research work. But how much better their research knowledge will be if they have had shop training and experience.

MEMBER: What procedure should apprentice instructors follow in appealing to the boy's pride in workmanship other than holding out the possibility of becoming a foreman or supervisor?

MR. GOLDIE: The appeal to a boy's pride in workmanship is the production of a good casting. Appeal to him to produce a good casting. This

[6] President, Frank Foundries, Moline, Ill

casting he makes is going to go up to the machine shop and his pal is going to machine it. If his friend hits blow holes or sand holes, or anything else that may cause a defective casting, he is going to hear from him. We certainly recognize that as a point.

MR. BOULTON: I would like to make a comment on that. There are a lot of young men who go into industry and fall down and we think it is on the basis of lack of pride of workmanship. I would like to make the statement, and I think it is true, that a great deal of the trouble existing in apprenticeship work today, or has been over the past years, has not been due to the lack of instruction or lack of equipment. I think it has been due to poor selection more than anything else. If you do not select the right type of boy for the job, he ultimately will fall down. You may look at it on the basis of the fact that he is not fit because he spoils work or he does not have the proper attitude. You are never going to create the proper attitude in the young man unless he is properly selected for that particular type of work. If you base your whole program on proper selection, I think you will eliminate or eradicate a lot of trouble that has occurred in apprentice programs that has been blamed on lack of pride in work.

DEAN CONNELLEY: I consider a vocational counselor the greatest asset that a board of education has, and if they were properly selected, we could follow out exactly what Mr. Boulton has just said. We pay our superintendent $15,000, the assistants $10,000, $8,000, and so on, and we select a counselor, because he or she has been a teacher in a high school, and on account of his or her academic training. We do not select him for what the industry needs most, knowledge of the vocation which the boys will follow.

MEMBER: I am vocational instructor in a school in foundry work, and I do not believe any boy, if he is given an equal selection of any trade, will choose foundry work. I say if he is given a selection, if every trade is put up to him with a chance of getting a job in either one. The reason I say that is that with our educational system all the boys coming through that school have an opportunity to go through all the different shops the first year. At the end of that first year they select whichever trade they think they are suited for.

Now, it so happens that during the past 6 years, only 4 boys in our school selected foundry work. At the end of the year, I ask the boys "Who is interested in foundry work?" Very few have ever come out and said they wanted to take it up. When asked the reason why they were not interested, they tell me it is one of the most unhealthy jobs at which they could possibly work. That is, I think, the chief reason why foundries do not have apprentices today, because of the conditions under which they have to work.

B. WITTFOHT[7]: In relation to this talk on vocational schools, I have had the opportunity to talk to technical high school teachers, vocational instructors and counselors along the line of the trades the boys might take up, and they say that a boy does not know what trade he is going to take up, although he has an equal opportunity to study each while he is

[7] Foundry and Pattern Shop Instructor, Caterpillar Tractor Co., Peoria, Ill.

going to school. I think the reason why a boy does not take up foundry work is that the high school teachers and the vocational school teachers do not know what industry is doing. They have not been in a modern, up-to-date foundry. Here in Detroit, in fact in many foundries, you will find as clean and healthy conditions as in any other industry. The floor is as clean as it is here.

Many technical school teachers have said to me, "How do we know what to teach? We do not know what these boys are going to do; we do not know that they are going to work in a foundry."

I think it is part of the job of that teacher to find out while that boy is in his care what that boy is best suited for, and not just give him a general course and then say, "Here, get out and find a place in the world." It should be part of their training in the program to find out early in the stage what the boy wants to do, to take the boy on plant visits to various industrial plants where they have apprentice or other programs, and point out to him the various opportunities that the foundry presents. Competition is high in machine shops. Boys go into machine shops because it looks clean to them. But in the foundry competition is low. If you have any kind of an education at all, you are going to go to the top if you have the ambition to put it over.

MEMBER: I guess I am one of the youngsters here—I am just around the thirties now, but I would like to cite my experience. I knew I wanted to get into the foundry game, in spite of what has been said here. I liked the work and had always been intensely interested in it. I went through four years in a Chicago high school, and through five years in one of the Big Ten universities, and I had a hard time convincing anybody I was interested in foundry work. We had a wonderful dean at Purdue, Dean Potter, and we had as good a foundry school as any, but in the nine years after grammar school, I had only two courses of three hours each in foundry work. And when I was all buttoned up and started back to the foundry, I started in molding and picked up what I could on the side.

MR. GOLDIE: I would like to say a word about the remarks made about the dirty foundry. The foundries today are much cleaner than they were 10 or 15 years ago. Where I served my apprenticeship there was not even a place to wash up. You had to go home the way you were. My mother had to wash five suits of underwear a week. But do not let anybody tell you the foundry is not healthy.

MEMBER: I am a regular molder. I served my apprenticeship for four years with the Westinghouse Company in Canada, but I began the trade in Scotland. Conditions have improved. But because there has been some improvement in conditions over the past say 20 years in the foundry, it does not mean they have improved so much that they cannot be improved more. I know of foundries today where there are no lavatories. There is no place to wash. The men have to come out of that place with their faces black. Now, those conditions could and should be changed. If such conditions were changed, there would be plenty of young fellows eager to take up the job and learn it.

I know of some foundries that are very, very modern. They have showers and all conveniences in them. Those type foundries will attract apprentices but the other type will not.

Industrial Propane for Flame Cutting and General Foundry Use

By F. H. Andrews* and E. A. Jamison*, Philadelphia, Pa.

Abstract

For some years, liquified petroleum gases have been applied to industrial heating purposes. This paper deals with the application of propane to the foundry, especially for removal of gates and risers. The authors describe this fuel, giving its physical characteristics, B.t.u. content, availability, shipping methods and storage facilities required. The next section of the paper explains the use of propane as a flame cutting fuel, explaining the advantages and equipment necessary. The economics of oxypropane flame cutting also is discussed. The final section of the paper deals with the use of propane as a fuel in other foundry processes such as annealing, core baking, mold drying, ladle heating, preheating of electric furnaces, etc.

1. For some years liquefied petroleum gases have had steadily increasing application as industrial fuels, and the use of these gases for all types of heating processes has gained widespread recognition. Since this paper deals with those uses as applied to foundry work, especially flame cutting, only those heating processes applicable to foundry practice will be discussed.

2. Industrial propane, the principal liquefied petroleum gas marketed today, is obtained from natural gas or from oil refinery gases, through the medium of special fractionation equipment. The potential supply of this fuel is extremely large. Its constancy of composition, flexibility of utilization, high thermal value, and advantageous physical characteristics, make it an ideal fuel for general processing work.

Characteristics

3. Propane, chemical formula C_3H_8, is the third in the paraffin series of hydro-carbons. In its normal state, it is a gas. Because of its physical characteristics (initial boiling point of —50°

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F. and final boiling point of —40° F.), it is readily compressed into a liquid state. In this liquid form, it is transported from the refinery or other producing point to the place of use in specially designed tank cars or tank trucks. Tank car shipments are approximately 9,600 gallons, which is the equivalent of about 881,000,000 B.t.u.'s or 1,663,000 cu. ft. of 530 B.t.u. manufactured gas. In areas where trucking facilities are available, deliveries are made in 1000 or 2000 gallon lots.

4. Industrial propane is available to any plant which has a railroad siding regardless of its geographical location, and to others which may have no siding but which are located in a trucking area, and where the space requirements for storage can be met.

Equipment Required

5. The use of propane and the equipment required to handle it for plant use is relatively simple. A storage tank of sufficient capacity to receive tank car or tank truck shipments is installed at the plant either aboveground or belowground, and the vapor space of the storage tank is connected to the plant gas system. Since propane exerts a vapor pressure, approximately 120 lb. per sq. in. at 70° F., it is necessary to reduce this pressure to that desired for burner operation. This is usually done in two stages through conventional type gas regulators. Pressures for foundry use are generally from 14 in. water column pressure, for low pressure and atmospheric type of burning equipment, up to 30 lb. per sq. in. for the high pressure type. Vaporization of the liquid into a gas is accomplished in the storage tank itself or in a steam or hot water heat exchanger where the rate of use is very high.

6. Flame cutting of steel is not new. Those gases most commonly used with oxygen for metal cutting are acetylene, hydrogen, natural gas, manufactured gas and others. More recently propane has been found commercially economical for this purpose due to widespread distribution, low delivery cost, and excellent performance. For a number of years, due to availability, the lighter gases and liquefied petroleum gas mixtures have been successfully and economically used in the Pittsburgh steel district. In a good year one equipment company alone has shipped 100,000 cutting torch tips into this area for use with gases other than acetylene.

7. When industrial propane was first introduced as a cutting fuel, the results obtained were not wholly satisfactory, since suitable torch equipment had not been developed to handle the gas

efficiently. This resulted in high oxygen cost with no marked savings over other cutting gases, which were then most commonly used. Torch manufacturers have since perfected equipment which has entirely changed the picture. A number of plants which now use propane as a cutting fuel are showing definite reductions in cutting costs with superior operating results.

8. Although the theoretical flame temperature of acetylene in oxygen is approximately 5630° F., while that of propane is approximately 5280° F., the lower flame temperature and lower flame speed of the latter are of material benefit in most types of cutting operations. From a theoretical standpoint, the ability to easily produce an oxidizing type of flame with propane, explains in some measure the results achieved. The maintenance of an oxidizing type of flame with acetylene is not practical due to backfiring. It is especially interesting to note that sections of steel up to 34-in. thick have been successfully cut with the oxy-propane flame without the use of an oxygen lance.

TORCH TECHNIQUE

9. Since the oxy-propane flame has the ability to easily penetrate through heavy thicknesses of steel, it is apparent that torch technique should be adapted to this fact. Oxypropane cutters have found that the quickest and most efficient method of cutting is to cut parallel to the greatest thickness wherever possible. Also, to reduce preheating time, it has been found that cuts should be started at some point which presents a rough edge rather than a rounded surface. It has also been observed that the oxypropane flame does not require as clean a surface for the cutting operation as that required for the oxyacetylene flame. This means that the cleaning and chipping operation previous to cutting does not require the care or time previously required in preparing the castings for flame cutting.

10. For most efficient results, it is extremely important that the proper torch tip, hose, oxygen and fuel pressure regulators together with proper cutting procedure for propane be employed. Torches and tips designed primarily for acetylene will not do satisfactory work with propane.

11. For normal foundry flame cutting operations, where the gates and risers to be cut run up to 10-in. thick, a propane pressure of 7 lb. per sq. in. (obtained directly from the plant main without the use of boosters) and an oxygen pressure of between 40 and 60

lb. per sq. in. has been found to be satisfactory and efficient. It is worthy of note that the oxygen pressures used in propane cutting are much lower than required for similar acetylene cutting. Cutting risers 9-in. thick with 45 lb. per sq. in. oxygen pressure is common production practice with oxypropane. Tamper-proof regulators have been developed to hold oxygen pressures at desired points, the foreman in charge having a key to raise or lower pressures as desired. As the thickness of the risers and gates increases, it is necessary to increase oxygen and propane pressures to obtain efficient cutting. For general foundry work the most common pressure range for oxygen is from 30 to 90 lb. per sq. in., and for propane from 1 to 30 lb. per sq. in.

12. A cleaner and much narrower kerf is obtained with the oxypropane than obtained with oxyacetylene flame. This makes it evident that a much smaller volume of steel is being oxidized or burned away, and it is here that an oxygen economy becomes quite apparent. Every cubic inch of steel removed requires a definite amount of oxygen. A clean narrow kerf is most desirable from the cost standpoint. The oxypropane cutting torch produces a narrow kerf due to the somewhat lower flame temperature. Further the flame of the oxypropane cutting torch is not as reducing in character, hence does not tend to carburize or case-harden the edges of the metal being cut—a most desirable feature since machining costs are reduced and the metal retains its original quality.

Relative Costs

13. Statements have been made that propane would be too costly a cutting fuel even if supplied gratis. Such statements have been based upon limited tests indicating greater oxygen consumption and pre-heat time for propane. Statements based on such limited tests should not be used with reference to the entire range of materials to be cut and for all localities. Obviously, oxygen cost is the determining factor and this cost may vary widely at different localities. Furthermore, the ratio of pre-heat time to total cutting time must be taken into consideration since the oxygen used for cutting purposes is considerably less with propane than with acetylene. Foundries are interested in the actual cost per unit of salable product. The evidence, based on thorough tests and results of long time plant operations, is conclusive that propane can be, and is, used with substantial savings, especially over acetylene and hydrogen.

Table 1

EFFECT OF INDUSTRIAL PROPANE COSTS ON FLAME CUTTING OPERATIONS

Oxy-Acetylene Costs—Five Months Operation—Oct. '34 Thru Feb. '35.

	Carbide Cost	Depreciation on Acet. House and Generator	Heat for Acetylene Building	Maintenance Charges	Removal of Carbide Residue	Total Acetylene Charges	Total Oxygen Cost**	Total Net Tons Castings Produced	Oxygen and Acet. Cost Per Ton Produced
Total Cost for 5 Months...	$374.40	$59.75	$84.07	$15.00	$21.25	$554.47	$2821.53	727.0	$23.41
Average Cost Per Month..	$ 74.88	$11.95	$16.81	$ 3.00	$ 4.25	$110.89	$ 564.31	145.4	$ 4.68

Average Acetylene Cost Per Ton Produced.....$0.76
Average Oxygen Cost Per Ton Produced.....$3.92

Oxy-Propane Costs—Five Months Operation—Oct. '35 Thru Feb. '36.

	Propane Cost*	Depreciation of Propane Equipment	Heat for Oxygen Room	Maintenance Charges	Total Propane Charges	Total Oxygen Cost**	Total Net Tons Castings Produced	Oxygen and Propane Cost Per Ton Produced
Total Cost for 5 Months...	$ 85.86	$ 7.50	$28.55	$ 2.50	$119.41	$3642.12	818.76	$22.99
Avérage Monthly Cost....	$ 17.17	$ 1.50	$ 5.71	$ 0.50	$ 23.88	$ 728.42	163.75	$ 4.60

Average Propane Cost Per Ton Produced.....$0.148
Average Oxygen Cost Per Ton Produced.....$4.45

* Average Monthly costs based on an eleven day test during October, 1935.

** During the period of oxyacetylene cutting, 20 per cent of all gates and risers were cut on the sprue cutter. With oxy-propane cutting, sprue cutting was reduced to 5 per cent, and the area of those gates and risers formerly sprue cut was increased 15 per cent.

An analysis of these figures shows that oxygen consumption per unit of steel cut, was reduced approximately 8% with oxy-propane.

14. At one plant where propane was recently installed for general plant use, a properly engineered oxypropane cutting installation was also made. Table 1 shows the effect of propane cost on flame cutting operations. In each case these figures are averages for 5 months production and show the actual cost of the two as listed on plant records. At this plant, acetylene was generated and conducted to the torch stations in the plant through suitable distribution lines, until replaced with propane.

15. The carbide cost, depreciation on acetylene house and generator, heat for acetylene building, maintenance charges and removal of carbide residue, showed average costs per ton of castings produced as follows: acetylene $0.76, oxygen $3.92, and total oxyacetylene $4.68. For the same months of the following year the oxypropane costs are tabulated showing the propane cost, depreciation on propane equipment, heat for oxygen storage, maintenance charges, and the total oxygen cost. This shows costs per ton of castings produced as follows: propane $0.15, oxygen $4.45, and total oxypropane $4.60. These figures would tend to indicate that although the total cost is approximately the same, the oxygen cost per ton had increased.

16. However, during the period of oxyacetylene cutting, 20 per cent of all gates and risers were cut on the sprue cutter. Simultaneous with the change to oxypropane cutting, sprue cutting was reduced to 5 per cent, due to the new methods of gateing and heading. The area of the gates and risers formerly cut on the sprue cutter was increased 15 per cent. Therefore, this increased production was obtained at no increase in cost. An analysis of the data in Table 1 shows that the oxygen consumption per ton with oxypropane, was reduced approximately 8 per cent for a given unit of metal cut. This reduction in oxygen consumption of approximately 8 per cent has been obtained on other tests. It is, therefore, apparent that oxypropane cutting, instead of increasing the oxygen consumption per unit area of metal cut, actually decreases the oxygen consumption approximately 8 per cent.

17. The cost figures in the comparison are based on a production of some 600 to 800 castings per day. It would be well at this time to point out that the same operators were used on both the oxyacetylene and oxypropane work during the period of comparison, and that these men readily became familiar with oxypropane torch technique. It usually requires the average torch operator about one week to become familiar with using the oxy-

propane torch. Therefore, some patience is required for proper manipulation.

18. Equipment costs are considerably reduced with oxypropane cutting, since torch tip life is increased approximately 200 per cent. Also the cost of the propane tip is only about one-half the cost of the acetylene tip.

OTHER USES

19. The use of propane for flame cutting is only one of many applications in a foundry in which it can be profitably utilized. Other important applications are: (1) Annealing castings, (2) Baking cores, (3) Melting non-ferrous metals, (4) Pre-heating electric furnaces, (5) Drying molds, (6) Heating ladles, (7) Miscellaneous uses such as space heating, water heating, laboratory, etc.

20. For annealing castings, propane has replaced oil in a number of instances, to obtain close control over scaling conditions and temperature of operation. This was not possible with oil except under close and costly supervision. With operation on propane, temperature and atmospheres can be closely regulated through suitable automatic controllers, thus the life of refractories is considerably increased, resulting in lower maintenance charges and better quality work.

21. When applied to core baking operations, again temperature control, uniform heat and better working conditions is the result. This means fewer burned cores, better quality cores and the entire elimination of smoke and fumes always attendant on lighting up a cold oven with oil.

22. For skin drying of molds, propane has proved an ideal fuel, because of favorable physical characteristics. When the mold drying torch is set fairly rich, the heavier air-gas mixture (specific gravity of propane gas is 1.52) penetrates through every portion of an intricate mold, especially molds placed below floor level, and dries out those portions which are practically impossible to reach with other methods. A drying depth of 6 ft. is easily obtained by this method. High pressure propane equipment with a small hose connection to the burner making a light, portable torch, is generally used.

23. The application of a gaseous fuel to ladle heating can result in savings not at first apparent. In one instance an oil-fired unit with a single burner, consisting of a rectangular firebrick box on top of which were six openings, over which small

ladles were placed and heated, was replaced with a specially designed propane-fired bench with small high pressure burners under each ladle. This method of application reduced the heating-up time 50 per cent and 1¼ gallons of propane did the work of 3½ gallons of fuel oil. On larger ladles comparative results were obtained with the entire elimination of smoke usually accompanying the oil operation.

24. Where pre-heating electric furnaces should be considered because of the power factor and high demand, propane is an ideal fuel. At one plant where the power cost necessitated operating between the periods of 7 P. M. to 7 A. M., propane was used to pre-heat the charge in the furnace previous to the first melt. This resulted in lowering the time of the first heat sufficiently so that one additional heat per night was obtained. The savings in time and labor, plus the increased production obtained, more than offset the cost of the propane used.

25. At one plant (see Table 2), records show that the combined fuel cost per ton was $17.66, which included fuel oil cost on all operations, acetylene and oxygen cost on cutting operations, city gas cost on core ovens and miscellaneous operations, and electric cost on steel melting. When propane was installed, it was used to replace practically all of the fuel oil, all acetylene, all city gas, and also used to pre-heat the electric furnace previous to the first melt. Also after all conversion, the net total cost per ton was $16.69 or an average reduction of $0.97 per ton with attendant labor saving, increase in refractory life, much lower maintenance cost, elimination of oil fumes, closer control of temperature and fewer rejections. The price paid for the various fuels was comparable to those that prevailed throughout the country.

Summary

26. Because of its proved performance industrial propane is economical for use with oxygen for cutting purposes particularly where large quantities of cutting fuel are required or where other fuel applications exist, thus amortizing the cost of equipment in a reasonable length of time.

27. Industrial propane is an extremely flexible fuel for general foundry use. Its high B.t.u. value, and choice of available pressures, without the use of boosters or compressors, enable it to be carried through very small pipe lines in sufficient volumes for

Table 2

EFFECT OF INDUSTRIAL PROPANE COSTS ON GENERAL FOUNDRY FUEL USE

Total Fuel Costs—Before Installation of Industrial Propane
Five Months Operation—Oct. '34 Thru Feb. '35

	Fuel Oil Cost	Acetylene Cost	City Gas Cost	Electric Melting Cost	Oxygen Cost	Propane Cost	Net Tons Castings Produced	Average Cost of All Fuels Per Ton
Total Cost for 5 Months...	$1960.69	$554.47	$733.56	$6804.46	$2821.53	.....	727.0	.....
Average Monthly Cost....	$ 392.14	$110.89	$146.71	$1360.89	$ 564.31	.....	154.4	.....
Average Cost Per Ton.....	$ 2.76	$ 0.76	$ 1.02	$ 9.27	$ 3.90	.....	.....	$17.66

Total Fuel Costs—After Installation of Industrial Propane
Five Months Operation—Oct. '35 Thru Feb. '36

Total Cost for 5 Months...	$ 746.38	.....	.....	$6812.07	$3642.12	$2400.54	817.8	.....
Average Monthly Cost....	$ 149.28	.....	.....	$1362.41*	$ 728.42	$ 480.11	163.6	.....
Average Cost Per Ton.....	$ 0.91	.....	.....	$ 8.39*	$ 4.45	$ 2.95	.....	$16.69

* Propane used to preheat electric furnace charge prior to first melt. Result—increased production and labor-saving.

plant utilization. The specific gravity is constant, and uniform pressures are easily maintained.

28. It is readily adapted to single, conventional type of control equipment, at lower equipment cost since smaller control valves may be used. There is no chance for sludge or water entering the system as in the case of oil. The material itself is of a high purity and practically free from sulphur, enabling it to be used on delicately controlled atmosphere heating operations. Smoke, soot, and dirt, due to fuel operations, are entirely eliminated, hence from a maintenance and operating standpoint it is an ideal fuel.

29. Results show that a foundry can change much of its process heating operations to the use of propane and obtain not only a lower cost per unit of salable product, but also increase the quality of the product and general working conditions. Availability, low cost, flexibility, cleanliness and ease of handling, make propane a fuel which justifies serious consideration by plant executives and engineers.

DISCUSSION

F. A. MELMOTH[1]: I believe this paper should have been accompanied by another one by the acetylene authorities for there is a strong element in the paper which suggests the author is very much in favor of propane.

The author made a remark in connection with tips for burners for using propane which may very satisfactorily answer the remarks I am going to make. We have tried propane. Admittedly the trial was not a very long one. Maybe it should have been longer. It was made some little time ago. But our experience was this: Taking fairly heavy sections, where the preheating time to start the cut was not materially significant to the total time required to make the complete cut, the comparison with acetylene was about even. But there is another side to steel castings. That is the smaller and medium size, where the time taken to start the cuts is really critical. Here one is making many thousands of cuts per working day, and our experience, very carefully checked with a stop watch, was that the preheating time, that is, the time before the actual fusion of the metal to make the cut took place, was disproportionately longer with propane than with acetylene. I might add we used tips which were suggested by the people who sold the propane.

It can be noticed that point was dealt with by the authors' remark that judgment had been passed on propane on the results from inexperienced operators which was not necessarily satisfactory. I think in fairness to acetylene it is necessary to state those facts.

MAJ. R. A. BULL[2]: If I understood Mr. Melmoth correctly, his last

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[2] Consultant on Steel Castings, Chicago, Illinois.

remark appeared to be contradictory to the one the author made in his paper when he spoke of the fact that it was not necessary to do as thorough cleaning of the surface of the casting for cutting with propane as with acetylene. I would construe that as being opposed, in effect, with the comment just made by Mr. Melmoth. Would you not think so, Mr. Melmoth?

MR. MELMOTH: No, I do not agree with that. I think the difference was due to the heat intensity of the flame. Supposing we were making a small cut, say 1½ or 2 in., it would probably take from 15 to 17 seconds to heat it up with propane, whereas with acetylene it would be a matter of 3 or 4 seconds, the cleanliness being the same in each case.

It did not take any longer to do the actual cutting with propane, but the period taken to reach the cutting point was longer due to the absorption of heat from the flame into the casting. We timed it with stop watches and it consistently took longer to bring the point of contact of the flame on the casting to the necessary temperature. After that, the cutting was at about the same rate.

MAJ. BULL: I am prompted to ask the author why the propane-cut casting does not have to be cleaned as thoroughly as the acetylene-cut casting?

MR. ANDREWS: I will try to take up both of these points in general. We are talking about over-all cost, that is, taking into consideration the total over-all cost of cutting both light and heavy castings, and the only thing I wanted to bring out is that the over-all cost is lower and that propane fuel can be substituted for acetylene at some saving. Now, the figures taken from the plant show that we can substitute propane for acetylene, even on very small castings, as well as on large castings. Admittedly there is a difference in the heating-up time between propane and acetylene, in favor of acetylene. But, taking the total day's cost for propane, we merely wish to show that the actual over-all cost was lower than with acetylene. We used the same operators in making the comparison, the same types of castings, and figured our results on the total tons produced. That, of course, is the cost in which any plant is interested. You are not interested particularly in the cost per hour or per day if the total, over-all cost at the end of the month is something entirely different. And what we have tried to do is take a period of operation for a long time and show that acetylene can be replaced with propane at some saving.

MR. MELMOTH: That is equivalent to saying if we now had four cutters, and the total time taken for cutting is longer because the preheating time is longer, we merely have to put on five cutters to keep our production balance, which is necessary. You must keep the same quantity going forward. If we put an extra man on, we must charge the extra man against other savings introduced by the use of propane.

MR. ANDREWS: No additional men were used for propane cutting. The same cutters performed and man-hours were practically the same. In cutting operations on castings, you will not find that difference which I think you ran into at the time you made your tests, which you said was about a year ago.

Since that time, there have been developments. Now, on dirty castings, for instance, propane will actually start and do the cutting quicker than acetylene. That is one example of where there is a saving in time. A casting must be cleaned quite well before you can start with acetylene flame. Propane will start on dirtier castings and in that way some time is saved. So that, when you take the over-all cost, you obtain better results than you would get, with a stop watch, where both castings are the same. In fact, in one plant I know they are thinking of cutting out some of their cleaning operations because of that fact. How well that will work out and how far we can go with that is problematical as yet. If we can eliminate one or two cleaning operations and save labor there, that means something.

MR. MELMOTH: By dirty castings, I presume you refer to adhering sand. What is the theory of the improvement in the case of propane?

MR. ANDREWS: I cannot answer your question. All I know is that it does it.

CHAIRMAN J. H. HALL[3]: Can you give us any answer to Major Bull's question as to why propane cutting needs less cleaning?

MR. ANDREWS: I think what I mean there was not stated in those exact words. What I meant was that propane cutting can be made on originally dirtier castings than with acetylene.

MAJ. BULL: I understand that, but why is that?

MR. ANDREWS: I am afraid I cannot answer that.

MEMBER: Is it because you have an oxidizing flame?

MR. ANDREWS: That is one of the reasons. But that does not wholly explain that particularly fast starting on dirty castings. When you ask me for that information, I would like to give you a definite statement, but I cannot do it. The fact you can produce an oxidizing flame with propane is one of the reasons you can start a cut on a dirty casting. While with acetylene you must carry a different type of flame. You cannot produce that oxidizing flame, with acetylene without back-firing the torch. You can get that result with city gas for starting, or some of these other gases, because of the fact you can produce oxidizing types of flame.

C. S. ROBERTS[4]: We have been using propane. If I had any criticism of this paper, it would be perhaps that the author over-emphasized the use of propane for cutting. In our case, we put in propane as a fuel gas and used it only incidentally for cutting when we found it was usable for that purpose, and we were very pleasantly surprised on our results. It is certainly easier to tap in on a gas line in the plant than to take care of an acetylene generator.

In comparing propane for cutting, one must remember that it is a new tool. When you put it up to men who have operated with acetylene, or men who are accustomed to acetylene flames and their adjustment and, because a propane flame gives an entirely different appearance when it

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is properly adjusted, you will find men trying to get the same type of flame with propane they did with acetylene, and it does not work. By the end of the second day, our cutters were ready to give up in disgust, but after about 10 days they said they would not care to go back to acetylene.

I would say it would take fully a month for the average type of labor you have with the cutting torch, to begin to get the best results from propane.

As I say, as a general foundry fuel, it seems to us to be almost ideal. And particularly so on a cold winter morning. I believe you have all had the experience of lighting up a cold oven or furnace or trying to heat a cold ladle, filling the shop full of smoke and fumes, particularly on a ladle where you do not have ideal conditions. It may be an hour before your oil burner is really doing business. With propane, it is doing business as soon as you light it. That is one of the reasons for the saving on fuel.

As to the starting time on propane cutting, as brought up by Mr. Melmoth, where you have a large number of small castings, naturally the section is smaller and the differential in the time of starting a cut with acetylene is correspondingly smaller. But the cutters, after they get accustomed to propane, have some tricks in picking a rough spot, as Mr. Andrews pointed out, getting one point incandescent, and we have found very little difference in the starting time after the operators get accustomed to the use of propane.

Molding Sand in the Malleable Iron Foundry

By H. W. Dietert* and Frank Valtier**, Detroit, Mich.

Abstract

At the request of the A.F.A. Malleable Committee, the authors undertook an investigation of the properties of sands used in malleable cast iron foundries. Samples of sand from 13 foundries were secured and with these samples information as to their use was secured. These sands were tested by the authors and the test data are plotted, showing various relations of sand properties to effects on castings produced. Some of the outstanding conclusions reached are: That synthetic sands are being used to a considerable extent; for smoothest casting surfaces, sands with low permeabilities are desired and an approximate relation may be established between permeability and smoothness; pyrometric control of metal temperature is now general in malleable foundries. The authors discuss in detail the relationships shown by the data secured.

1. Sand test figures are of practical value when one knows the proper value of such figures for each class of castings. They are also of importance for use in holding the condition of the sand constant so that the bad effects of varying sands are eliminated. When test figures are used for this two-fold purpose of establishing a suitable and maintaining a non-varying sand, then sand control is practical and profitable.

Purpose of Survey

2. In any one foundry, it is possible to correlate the test figures of the sand used to mold the different classes of castings. To determine whether this same correlation would hold true, and prove of practical value, test figures of sand used in a large group of malleable iron foundries were considered. An investigation was undertaken and samples were secured of two different sands

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used in thirteen malleable iron foundries. With the request for samples, a questionnaire was sent to be filled out asking for information as to the conditions under which the sand was used and also the nature of castings produced in the sand.

The questionnaire requested data to be filled in as follows:

SAND SAMPLE NO.....

Natural Sand.... Synthetic Sand....
Other Additions: Sea Coal..... Pitch..... Cereal Binder.....
Sand Mixed by: Sand Cutter..... Pug Mill..... Shovel.....
Royer..... Beardsley Piper, etc.....
Is Sand Riddled before Placing on Pattern? No..... Yes.....
Size of Riddle.....
Sand Used as: Facing..... Backing..... All Facing.....
Sand Used on Floor..... Sand Used in Sand System.....
Sand Rammed by: Hand..... Hand Squeezer..... Jolt.....
Squeezer-Jolt..... Pounds of Air.....
Air Squeezer..... Pounds of Air on Piston.....
Size of Piston.....
Sand Slinger.....
Size of Flask, Length, Width, and Depth: Minimum..... Maximum.....
Are Sides of Flask Vented? Yes.... No....
Strainer Cores used in Sprue..... Cored In-gates Used.....
Mold Dust Used: Graphite..... Cement.....
Mold Wash: Graphite..... Silica.....
Weight of Castings Sand is Prepared for: .....lbs. to .....lbs.
Thickness of Casting Wall: Minimum.....inches—Maximum.....inches
Predominating Casting Wall Thickness: .....inches.
Temperature of Metal Poured: .....degrees Fahr.
How Measured: .....Corrected for Emissivity: Yes..... No.....
Alloys Added and Amount: ....
Sand Casting Finish: Smooth..... Medium..... Rough.....

METHOD OF TESTING THE SAND

3. The sand samples were all received in sealed containers and conditioned as used in the foundry. The sand samples were tested as received for moisture, permeability, green strength, deformation, dry strength, clay content and fineness.

4. The equipment and procedure for testing the sand samples were in accordance with A.F.A. specifications. The equipment used in the various tests was as follows:

Moisture Test: Moisture Teller, Balance.

Permeability Test: Sand Rammer, Permeability Meter.

Strength and Deformation Test: Universal Sand Strength Machine, (motor driven with deformation accessory).

Clay Content and Fineness Test: Rapid Sand Washer, Testing Sieves, Gyratory Sifter, Drying Oven.

5. The test figures for the sand samples are shown in Table 1 with the exception of the fineness data which are shown in Table 2. The test data are grouped substantially in order of weight of casting cast in the sand from the lightest to the heaviest. A detailed study of the data tabulated yields many correlations between the sands used in the different foundries and castings made.

Summary of Sand and Foundry Conditions

6. The general sand and foundry conditions prevailing in these thirteen malleable iron foundries is summarized in Table 3. Some of the many interesting facts as developed by the data of this table are worthy of brief discussion.

Kind of Sand

7. Whether natural or synthetic sand is better adapted for a certain class of castings is receiving much consideration by foundrymen at the present time. Eleven of the sand samples submitted were synthetic sands and 15 were natural sands. All the synthetic sands had a fineness number of less than 100. All sands with a fineness greater than 100 were natural sands, showing that natural sands were used when a very fine grain structure was required.

Facing

8. A few years ago the practice of preparing the entire sand heap as if it were facing became quite extensive among iron foundrymen. In malleable iron foundries, where pouring temperatures are high, one would not expect this practice to be very extensively used. However, nine samples were submitted where all facing sand was used, while 11 samples were facing sand samples. The pressure applied for reduction in cost will undoubtedly lead others to follow this newer practice.

Refractoriness

9. The refractoriness of molding sand is much lower than many realize and causes casting finish to be much inferior to what might be obtained if high refractory molding materials were available. Sea coal improves the refractoriness of molding sand and,

Table 1

SAND TEST FIGURES AND FOUNDRY CONDITIONS FOR SAND SAMPLES SUBMITTED

Sample Number	Moisture, Per Cent	Permeability, AFA No.	Green Compression, lb. per sq. in	Green Shear, lb. per sq. in.	Dry Compression, lb. per sq. in.	Deformation, in. per in.	Clay, Per Cent	Type	Av. Casting Thickness, in.	Wt. of Casting, lb.	Sand—Kind†	Method of Ramming	Type of Molding	Type of Mixer	Additions to Sand	Casting Finish	Metal Temperature Deg. F.
1	6.3	8.7	6.30	1.30	35	0.012	11.2	All Facing	5/8	0.02 to 1.0	Nat.	Squeezer	Floor	Sand Cutter	....	Smooth	2775
2	7.3	26.0	8.00	1.60	55	0.016	15.2	Facing	3/8	0.01 to 1.0	Syn.	Squeezer	Floor	Sand Cutter	Sea Coal	Smooth	....
3	5.9	14.1	4.65	0.73	17	0.016	11.2	Facing	3/8	0.1 to 0.5	Nat.	Squeezer	Floor	Sand Cutter	....	Smooth	2900
4	6.4	21.5	4.25	0.90	23	0.015	12.0	Facing	3/8	0.5 to 0.75	Nat.	Hand	Floor	Sand Cutter Muller	....	Smooth	2900
5	5.2	10.2	10.15	1.90	58	0.010	14.2	Facing	3/8	0.12 to 0.5	Nat.	Hand	Floor	Sand Cutter	Sea Coal	Smooth	2800
6	8.5	15.0	6.65	1.35	60	0.024	13.6	All Facing	1/4	0.02 to 5.0	Nat.	Squeezer	Floor	Sand Cutter	....	Smooth	2600
7	7.0	9.6	7.00	1.67	72	0.023	16.4	Backing	1/8	0.3 to 16	Nat.	Squeezer	Floor	Sand Cutter	....	Smooth	2850
8	6.4	16.0	7.60	1.90	26	0.015	12.4	All Facing	1/2	0.5 to 10	Nat.	Squeezer	Floor	Sand Cutter	....	Medium	2600
9	5.1	42.5	7.10	1.30	40	0.016	11.4	All Facing	1/4	0.05 to 10	Syn.	Squeezer Jolt	System	Pug Mill	Sea Coal	Smooth	2675
10	4.9	38.0	8.40	1.80	152	0.017	11.2	All Facing	1/4	2 to 10	Syn.	Jolt	Floor	Sand Cutter	Sea Coal	Smooth	2750
11	5.6	66.0	5.20	1.15	72	0.025	12.4	Backing	5/8	0.2 to 2.5	Syn.	Squeezer	Floor	Sand Cutter	....	Medium	2750
12	5.2	43.0	5.20	1.10	45	0.021	9.0	Backing	5/8	0.2 to 2.5	Nat.	Squeezer	....	Sand Cutter	....	Medium	2750
13	5.4	20.4	6.50	1.50	13	0.019	12.2	Facing	3/8	10 to 13	Syn.	Squeezer Jolt	Floor	Pug Mill	Sea Coal	Smooth	....

14	8.0	44.5	3.50	0.75	88	0.023	9.2	All Facing	¼	5 to 15	Nat.	Squeezer	Floor	Sand Cutter Muller	....	Medium	2775
15	4.8	28.2	9.95	2.00	183	0.017	17.2	Facing	½	1 to 20	Nat.	Hand Squeezer Jolt	Floor	Sand Cutter	Cereal Sea Coal	Medium	2800
16	5.4	59.0	6.50	1.35	73	0.017	13.0	All Facing	¼	0.5 to 25	Syn.	Squeezer	System	Pug Mill	Sea Coal	Medium	2750
17	4.8	42.0	7.20	1.30	38	0.018	11.5	All Facing	¼	4 to 44	Syn.	Squeezer Jolt	System	Pug Mill	Sea Coal	Smooth	2675
18	6.4	50.0	8.50	2.40	214	0.023	11.6	Backing	¼	30 to 50	Nat.	Hand Jolt	Floor	Sand Cutter	....	Medium	2850
19	5.1	48.0	9.17	2.40	133	0.016	12.1	Facing	½	10 to 60	Syn.	Jolt Hand	Floor	Pug Mill Royer	Sea Coal	Smooth	2750
20	9.0	24.8	4.00	0.92	55	0.024	12.0	Facing	⅝	up to 40	Nat.	Squeezer Jolt	Floor	Sand Cutter	Sea Coal	Medium* Smooth	2850
21	7.0	24.0	7.45	1.70	89	0.022	14.2	Facing	½	1 to 40	Syn.	Squeezer	Floor	Sand Cutter, etc.	Sea Coal	Medium	....
22	3.6	37.0	5.50	1.20	77	0.020	10.2	Facing	1	5 to 85	Nat.	Squeezer Jolt Hand	Floor	Sand Cutter	Sea Coal	Medium	2750
23	6.0	22.8	9.20	1.15	162	0.022	15.6	Facing	½	30 to 240	Syn.	Squeezer Jolt	Floor	Pug Mill	Cereal Sea Coal	Medium	....
24	7.4	40.7	3.00	0.67	18	0.027	11.0	Backing	⅜	10 to 100	Nat.	Hand Squeezer	Floor	Sand Cutter	....	Medium**	2850
25	5.6	28.4	8.90	2.30	75	0.018	16.6	Facing	1	90 to 180	Nat.	Squeezer Jolt	Floor	Muller Royer	Sea Coal	Medium	2700
26	4.7	87.0	8.80	2.07	69	0.020	12.6	All Facing	⅜	25 to 270	Syn.	Jolt	System	Muller	Sea Coal	Medium	2750

*Mold finished with graphite, silica wash.
**Mold given graphite wash.
†Nat.=Natural; Syn.=Synthetic.

Table 2

FINENESS TEST DATA AND A.F.A. FINENESS NUMBER OF SAND SAMPLES SUBMITTED

Sample Number	Per Cent Material Remaining on Respective Sieves												A. F. A. Fineness Number	Per Cent Fines*	Kind of Sand**
	Sieve No. 6	Sieve No. 12	Sieve No. 20	Sieve No. 30	Sieve No. 40	Sieve No. 50	Sieve No. 70	Sieve No. 100	Sieve No. 140	Sieve No. 200	Sieve No. 270	Pan			
1	0.0	0.4	2.0	1.8	11.2	1.6	17.0	5.6	6.4	6.8	9.0	27.0	148	42.4	Nat.
2	0.1	2.1	3.0	3.9	9.6	3.8	28.3	8.8	10.2	5.2	2.6	7.2	83	13.8	Syn.
3	0.6	1.6	1.0	1.5	7.0	2.3	20.3	11.3	12.5	7.3	6.8	16.8	122	28.8	Nat.
4	0.0	0.2	1.7	1.5	7.1	3.1	21.0	11.8	13.2	7.4	5.4	15.6	118	24.6	Nat.
5	0.0	1.8	0.8	1.2	5.2	1.4	13.8	8.2	5.2	10.8	18.4	19.0	151	48.2	Nat.
6	1.8	0.4	1.6	1.4	4.0	1.6	14.2	6.6	14.2	26.2	7.6	6.8	116	40.6	Nat.
7	0.0	1.4	0.2	1.3	8.1	3.6	21.4	7.6	10.8	8.4	6.8	14.8	117	29.2	Nat.
8	0.0	0.6	0.8	1.6	8.0	0.2	22.8	10.6	12.4	10.6	8.0	12.0	115	30.6	Nat.
9	0.0	0.4	0.0	0.5	1.7	1.2	28.8	27.2	19.7	5.7	1.2	2.2	80	9.1	Syn
10	1.3	0.5	0.6	1.0	6.0	2.2	41.4	10.0	13.0	6.4	3.2	3.2	77	12.8	Syn.
11	0.0	0.2	0.1	0.5	5.6	7.2	48.8	3.7	6.3	5.0	3.2	7.0	83	12.4	Syn.
12	0.0	0.2	0.2	0.5	6.1	4.2	47.3	6.7	6.C	4.2	6.0	9.1	91	19.8	Nat.
13	0.0	0.4	0.6	2.2	13.4	4.3	22.9	7.6	13.0	11.6	6.0	5.8	93	23.4	Syn.
14	0.0	0.7	1.5	2.2	10.1	4.0	31.5	12.0	9.2	4.0	3.6	12.0	96	19.6	Nat.
15	0.0	0.4	0.4	1.4	18.2	0.8	8.2	32.6	7.4	4.2	2.8	6.4	85	12.4	Nat.
16	0.0	0.2	0.5	2.1	6.2	1.2	43.8	18.0	8.8	2.2	1.4	2.6	70	6.2	Syn.
17	0.0	0.0	0.2	0.3	1.5	1.2	26.2	28.4	21.0	6.7	2.0	0.9	80	9.6	Syn.
18	0.1	0.1	0.3	2.2	14.6	4.7	41.5	6.8	8.6	4.0	2.2	3.3	69	9.0	Nat.
19	0.0	0.4	0.7	1.4	7.5	3.4	48.4	11.5	8.9	3.4	1.4	0.8	88	5.6	Syn.
20	0.4	0.4	0.4	0.6	2.4	1.4	22.0	10.6	21.0	11.8	7.8	9.2	114	28.8	Nat.
21	0.0	1.0	2.3	4.1	11.9	3.8	29.3	8.3	8.4	4.9	3.0	8.7	87	13.3	Syn.
22	0.0	0.4	0.5	1.0	6.9	3.8	40.3	14.5	9.2	3.0	2.1	8.1	85	13.2	Nat.
23	0.0	0.3	0.3	1.6	16.8	5.6	37.0	7.6	5.2	2.6	1.2	6.2	73	9.0	Syn.
24	0.0	0.7	0.9	1.4	5.2	2.2	39.2	11.6	11.8	6.2	4.2	5.6	86	16.0	Nat.
25	0.9	0.9	0.2	1.0	5.8	1.7	36.3	13.0	8.7	2.8	2.2	9.9	92	14.9	Nat.
26	0.0	0.1	1.5	9.4	17.0	2.0	34.6	12.0	7.0	1.6	0.8	1.4	55	3 8	Syn.

** Nat.=Natural Sand, Syn.=Synthetic Sand.

*Material Remaining on 200, 270 and pan mesh in Fineness Test

Table 3

Summary of Sand Test Figures and Foundry Conditions

Condition	Number Reported
Synthetic Sand	11
Natural Sand	15
Sand used as facing	11
Sand used without facing	9
Sand used on floor	22
Sand used in system	4
Sand prepared with sand cutter	17
Sand prepared with pug mill	6
Sand prepared with muller	4
Sand prepared with areators	3
Sea Coal Additions	15
Cereal Binder Additions	2
Mold wash or dust	2
Optical Pyrometer Temp. Readings	22
Smooth finish	12
Medium finish	13
Rough finish	0
Samples containing more than 25% fines	6
Samples containing less than 10% pan	19
Samples containing 10 to 15% pan	3
Samples containing more than 15% pan	4
Samples containing largest amount on 70 sieve	21
Samples with permeability less than 10	2
Samples with permeability 10 to 20	4
Samples with permeability 20 to 40	10
Samples with permeability 40 to 90	9
Samples with green compression less than 6.5	11
Samples with green compression more than 6.5	13

in quantities, as usually added to molding sand, raises the resistance to heat effects about 100° F.

10. Of the 26 samples, 15 were submitted to which sea coal was added, leaving six samples for use against the pattern without sea coal and five samples to be used for backing sands. Only two samples were submitted that contained cereal binder which was added in conjunction with sea coal. It was expected that more foundries would report mold wall treatment to improve the finish of the castings. Only two samples were submitted where mold dust or wash was used.

11. The prominence of pyrometers available for measuring the temperatures of molten metal is of particular note. Of the 26

samples submitted, in 22 cases the metal temperature to which the sand was subjected was known by the use of an optical pyrometer. The temperatures reported ranged from 2675 to 2900° F.

Casting Finish

12. One request contained in the questionnaire was to indicate whether casting surface was smooth, medium or rough. This request brought out that twelve of the sands produced smooth finishes, thirteen produced medium finishes, and one medium smooth finish. No rough finishes were reported. The relation between the permeability of the sands and the reported casting

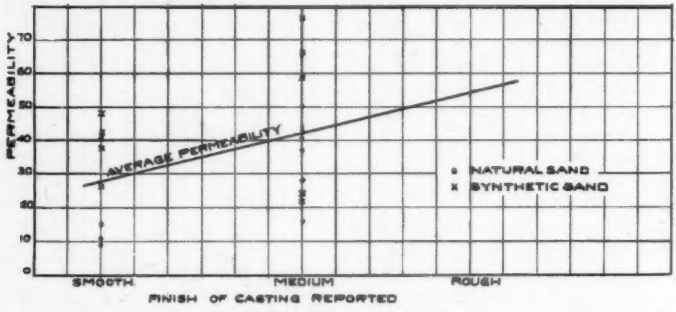

FIG. 1—THE RELATION BETWEEN PERMEABILITY AND REPORTED CHARACTER OF CASTING SURFACE.

finishes is shown graphically in Fig. 1. The average permeability of the sands reported producing smooth finishes was 27.7 while the medium finishes were made in sands with an average permeability of 42.5. This indicates that a low permeability is conducive to producing a smooth casting finish.

Fineness

13. The fineness data as shown in Table 2 show a wide variation in pan and fine material, but a remarkable uniformity in the medium grain size. The pan material of the synthetic sands was in each case less than 9 per cent, showing on an average much less fines than the natural sands.

14. Referring to Table 3, it may be noted that six of the samples contained more than 25 per cent of fines, or material which was retained on the 200, 270 mesh sieves and the pan. Nineteen of the samples contained less than 10 per cent pan material.

15. The 70 mesh sieve retained the largest amount of sand grains for 21 of the samples, showing that a malleable iron sand's most prominent sand grain passes a 50 mesh sieve and is retained on the 70 mesh sieve.

Moisture

16. The moisture of a molding sand is the greatest daily variable existing in the sand for it is added after each heat without measuring the quantity added. Practical and suitable water

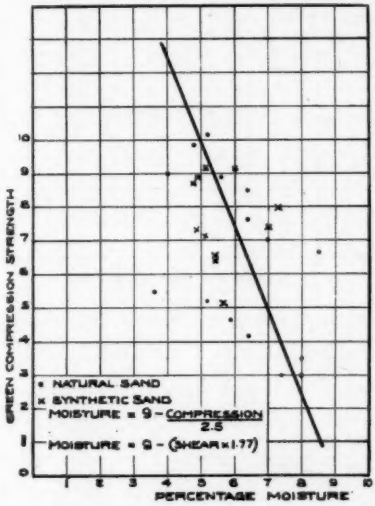
GREEN COMPRESSION STRENGTH
PERCENTAGE MOISTURE
• NATURAL SAND
× SYNTHETIC SAND
MOISTURE = 9 - COMPRESSION / 2.5
MOISTURE = 9 - (SHEAR × 1.77)

FIG. 2—THE RELATION BETWEEN GREEN STRENGTH AND BEST WORKING MOISTURE CONTENT.

measuring equipment and accurate moisture testing equipment should be used.

17. The percentage of moisture used in the sand samples tested ranged from a low of 3.6 per cent to a high of 9.0 per cent. This wide range is accounted for by the variation in strength and the fines of the sand. No relation exists between the moisture content and permeability, pan material or clay content.

18. The wide variation in moisture is best accounted for by the fact that the green strength of the sand varied greatly. Whenever the green strength is low, then it is advisable to work the sand heavy, or high in moisture. When the sand is worked

with a high green strength, then the sand is worked on the dry side of temper or at a low moisture percentage.

19. This is graphically illustrated in Fig. 2 where the moisture and green compression test figures are plotted. A straight line relation exists between compression strength and moisture. For example, the average condition for samples submitted shows that a sand with 10 lb. compression strength is worked with 5 per cent moisture, while a 4 lb. sand is worked with 7.4 per cent moisture. This relation may be expressed by the formulae:

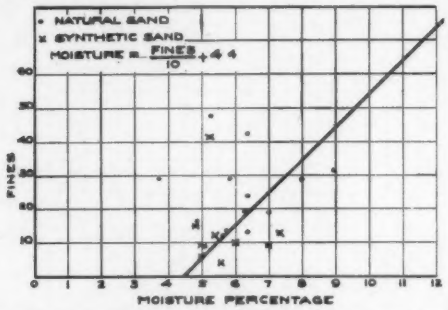

FIG. 3—CHART SHOWING RELATIONSHIP BETWEEN MOISTURE CONTENT AND PER CENT OF FINES (MATERIAL RETAINED ON THE 200, 270 AND PAN MESH) OF A SAND.

Formula E

$$\text{Moisture by Compression} = 9 - \frac{\text{Compression}}{2.5}$$

Formula F

$$\text{Moisture by Shear} = 9 - (\text{Shear} \times 1.77)$$

20. The amount of fines contained in a sand influences the percentage of moisture required to obtain the best workability of the sand. Since fines, *i.e.*, 200, 270 and pan mesh material, hold moisture, it is expected that the greater the fines the higher the moisture percentage.

21. The fines are partly measured by the strength test, since fines produce about 1/10 of the strength that clay substances do. The remaining portion of fine material that is not measured by the strength test affects the moisture and is accounted for by the formula:

Formula G

$$\text{Moisture by Fines} = \frac{\text{Fines}}{10} + 4.4$$

This relation holds substantially true for sand samples submitted as shown in Fig. 3.

22. The graph shown in Fig. 4 combines the effect of compression strength and fines on moisture content. This graph of Fig. 4 may be used to arrive at the theoretical moisture content of a natural sand or a sand bonded with clay. As an example; choose a sand with 25 per cent and 7.0 pounds compression strength. Draw line "*AB*". At the intersection "*O*" draw a vertical line to moisture at "*X*". Moisture reads 6.8 per cent.

23. The graph in Fig. 4 may be expressed by the formula H.

Formula H

$$\text{Moisture} = \frac{\text{Fines}}{20} + 6.7 - \frac{\text{Compression}}{5}$$

24. The Strength-Fines-Moisture graph shown in Fig. 4 will

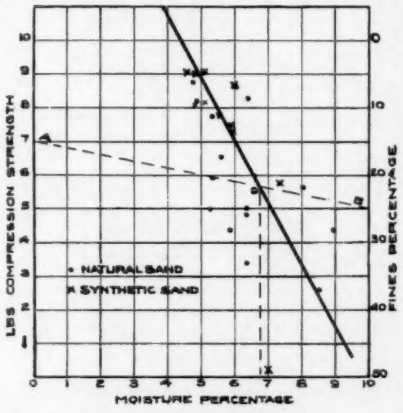

FIG. 4—STRENGTH—FINES—MOISTURE GRAPH.

in part answer the frequent inquiry as to the proper amount of moisture in a sand. Further refinement of this graph will prove helpful in the progress of sand control.

Permeability

25. The permeability of the sand samples submitted ranged from 8.75 to 87 A.F.A. permeability number. This range was used to produce castings which weighed from 0.01 to 270 lb.

26. The permeability required for a mold depends upon the mold depth, mold hardness, moisture percentage, casting wall

thickness and weight of casting. Assuming that mold depth does not exceed 8 in. and mold hardness be about 65, with moisture at the best workable percentage, then a graph as shown in Fig. 5 may be used to determine a probable permeability when average casting weights and wall thickness of a classified group of castings are known. Other permeabilities than those obtained from Fig. 5

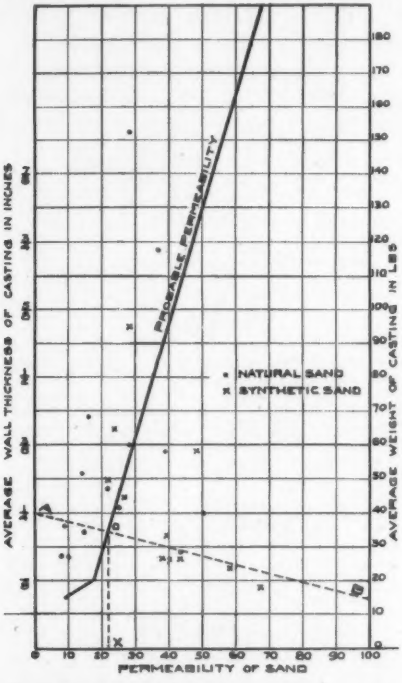

FIG. 5—GRAPH SHOWING PROBABLE PERMEABILITY WHEN AVERAGE WALL THICKNESS OF CASTING AND CASTING WEIGHT ARE KNOWN.

may be used but it is believed that the probable permeability values express an average condition and are practical for producing smooth castings. Application of this graph may be exemplified by the following: Average weight of castings to be made in the sand is 15 lb., and average wall thickness is 1/4 in. Draw a line between 1/4 and 15 as line *"AB"*. At the point of the intersection *"O"* draw a vertical line *"OX"* to permeability and read permeability as 21.

27. The A.F.A. fineness numbers and permeability values as

shown in Tables 1 and 2 may be plotted to show a fairly close relation, as shown in Fig. 6. This relation is of practical importance in that the permeability of a sand may be approximately determined when the fineness number of a sand is known by the use of the graph, Fig. 6, or by the formula C[1] which is:

Formula C

$$\text{Permeability} = 0.50\ S \left(\frac{714}{3+M}\right)^2$$

Where: S = 1.0 for round sand grains
M = A.F.A. Fineness Number

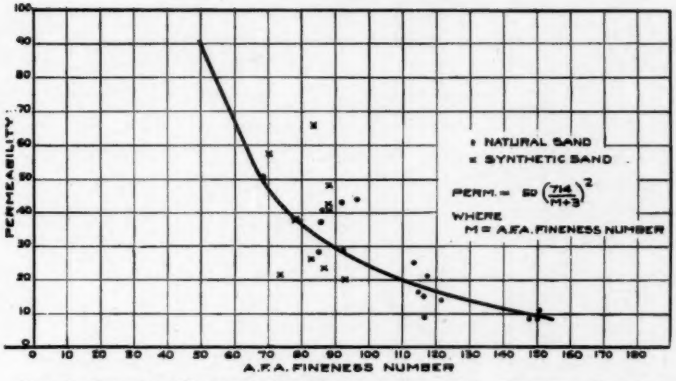

FIG. 6—RELATION BETWEEN PERMEABILITY AND A.F.A. FINENESS NUMBER.

Green Strength

28. The green strength required of a sand largely depends upon the flask and pattern construction and also on the depth of draw. This information was not secured from the various foundrymen so no comparison of this nature can be made. It should be recalled that the amount of moisture depends largely upon the strength of the sand, as shown in Fig. 2.

29. As a rule, the greater the A.F.A. clay content percentage of a sand, the greater the strength, which is illustrated in Fig. 7.

Dry Strength

30. The dry compression strength of the sand samples varied from 17.0 to 214 lb. No relation exists between the dry strength and the moisture content of the various samples.

[1] Dietert, H. W., and Valtier, F., *"Grain Structure and Mold Permeability Control,* TRANS. A.F.A., vol. 41, p. 184 (1933).

31. All of the sand samples used for producing castings heavier than 20 lb. possessed a dry compression strength greater than 30 lb., with one exception, sample No. 24.

Deformation

32. The deformation of a sand expresses the amount that a mold will swell when a load is applied equal to rupture load. The deformation of the sand samples tested ranged from 0.010 to 0.027 in, per in. Most frequently sands with a low green strength will show a high deformation.

33. Molding sand used for castings weighing more than 10

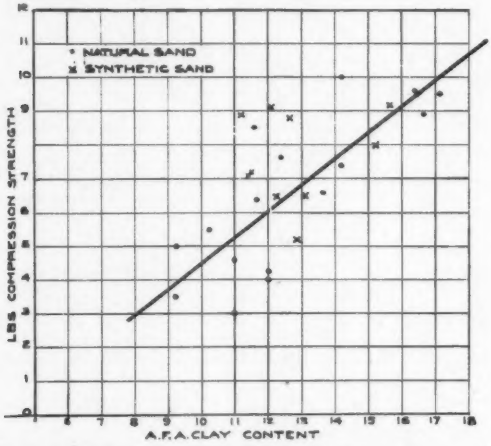

FIG. 7—RELATION BETWEEN GREEN COMPRESSION STRENGTH AND A.F.A. CLAY CONTENT.

lb., on the average, were molded in sand with a deformation of 0.016 in. per in. or better.

SUMMARY

34. The results of this investigation will be briefly summarized:

(1) Synthetic molding sands are used quite extensively in malleable iron foundries.

(2) Natural molding sands are used in a majority of malleable iron foundries and hold the field exclusively for molding sands finer than 100 A.F.A. fineness number.

(3) The ratio of 9 to 11 holds for comparing foundries

using an all facing sand against those using facing and backing sand.

(4) Of the 26 samples submitted, sea coal was added to 15 and 6 samples were used without sea coal where sand was placed against pattern. The remaining 6 were backing sands.

(5) The use of mold dust and mold wash was reported for only two sand samples.

(6) Of the 13 foundries reporting, 11 reported iron temperatures by optical pyrometers. Iron temperatures ranged from 2675 to 2900° F., which is considered a very small variation for a group of 11 foundries.

(7) The desirability of a smooth casting finish was attested by 12 sand samples producing smooth finishes, 13 producing medium finishes and none producing rough finishes.

(8) An approximate relation may be established between permeability and finish. A permeability of 27.7 according to average, will produce a smooth finish while a permeability of 42.5 will produce a medium finish and a rough finish would be secured with a permeability of 60.

(9) Synthetic sands contained less than 9 per cent pan material and on the average much less than natural sands.

(10) Of the 26 samples tested, 6 contained more than 25 per cent fines, *i.e.*, 200, 270 and pan.

(11) The sand samples contained 70 mesh material in most abundance with the exception of 5 samples.

(12) When sand is worked at high strength, a low moisture is desirable and, conversely, a low strength requires a high moisture. Formulae E and F were developed to show this relation.

(13) An increase of fines, *i.e.*, 200, 270 and pan mesh material, has a tendency to increase the quantity of moisture required. This relation is expressed by formula G.

(14) Since the strength and fines both influence the amount of moisture, a graph, Fig. 4, is shown whereby moisture required may be determined considering both of these two influencing items. Formula H may be used in place of the graph shown in Fig. 4.

(15) The permeability of sand samples submitted varied greatly due to large variation in the weight of castings molded.

(16) A graph is shown in Fig. 5 which may be used to

determine the probable permeability of a sand required when the average weight and wall thickness is known.

(17) The permeability of a sand may be estimated when the A.F.A. fineness number is known from graph, Fig. 6, or by formula *C*.

(18) The dry strength exceeded 30 lb. when castings molded exceeded 20 lb. with the exception of one sample.

(19) The deformation of the sand samples varied from 0.010 to 0.027 in. per in., undoubtedly due to the fact that no control is practiced as yet for this property of a molding sand.

(20) Sand used to mold castings weighing in excess of 10 lb. possessed a deformation greater than 0.016 in. per in.

35. Investigations of molding sands from various groups of foundries offer a most promising means of obtaining additional knowledge on sand control so necessary to the progress of the foundry industry.

DISCUSSION

MEMBER: Will Mr. Dietert explain more fully the relation between the deformation of sand and the lasting qualities?

MR. DIETERT: Deformation measures the amount the sand deforms when the load is applied. If the sand is brittle and a load is applied, it would not deform much and would break easily. For example, take two pieces of steel, both capable of carrying 100,000 lb. per sq. in tensile strength. One could withstand shock, being ductile, while the other, being brittle, would snap under shock. These steels could not both be worked at 50,000 lb. per sq. in. The ductile steel you could. The brittle one you could not; it would break the first shock it received. In other words, sand that has a higher deformation, has a longer life, from the angle of resisting shock loads.

MEMBER: In regard to the several references to iron temperature, I would like to know if any test has been carried on with this sand to determine low fusibility or high fusibility or the line of demarcation.

MR. DIETERT: We did not measure the sintering point of these sand samples. We still have the samples and we hope to measure the fusion point or the temperature at which the sand will burn on in the near future. But I believe that you would find, as you find all other sands, they would sinter at fairly low temperatures. By that I mean a temperature of around 2200 to 2300° F. Now, if you will refer to the figures in Table 1, you will find the very close relation in iron temperatures. For example, 2775, 2900, 2900, 2850, 2750, 2750, 2750° F., etc. a very close control of iron temperature. In pouring metal that runs around 2700° F. into the mould, the sand would be subject to temperatures of 2650° F.

I would say most of the sand samples submitted would not go above 2350° F. in sintering point. They would all "burn on" at 2350° F. In other words, sand is handicapped because it does not have enough refractoriness. We must find means of increasing the refractoriness of our sand to improve the casting finish.

MEMBER: At one place the author said we could tell the strength of the sand by the percentage of clay content.

MR. DIETERT: Yes. We can determine the approximate strength.

MEMBER: Does it make a difference which type of clay you use, a colloidal clay or more of a fire clay?

MR. DIETERT: Referring to Fig. 7, you will find that for the 26 sand samples, a fairly close relation exists between the A.F.A. clay content and green compression strength. Some of these sands were natural, others synthetic, yet on the average there was a close relation between A.F.A. clay content and green compression strength. There are a few cases where the agreement is not so close for some of the strong synthetic sands. In other words, they were the type you referred to, the plastic type or strong bonding type which would throw the relation off. But, on the average, the relation is very close. You could make a strong bonding clay and this graph would be incorrect.

MEMBER: In our work, we have some sand that runs 15 per cent clay and others that run 10 per cent. We get the same compression, but with different types of clay.

MR. DIETERT: Yes, that condition may exist.

MEMBER: In paragraph 8, there is a reference to using facing and also preparing the entire sand heap. The last sentence reads—"The pressure applied for reduction in cost will undoubtedly lead others to follow this newer practice." Which is the newer practice?

MR. DIETERT: What we refer to here in this paper as the newer practice is where all facing sand is used and no backing sand. Where we have the backing and facing sand, that is called the old practice.

M. J. LEFLER[1]: Is it possible, when using natural sand, to control fineness and consequently the finish on castings by means of a permeability test? In other words, if a permeability figure were set, that you wanted to stay near and when you got away from that standard figure adding either fines or coarser sand, would a permeability test be a sufficient test to keep out of trouble from finish or defective castings?

MR. DIETERT: I believe that a fineness test would be highly desirable if you were endeavoring to control the fines of your molding sand. I think it would be next to necessary.

MR. LEFLER: It would be much more expensive than running a permeability only, would it not?

MR. DIETERT: That is true, but unfortunately the fineness test gives you the detailed information you are after.

[1] Oliver Farm Equipment Co., South Bend, Ind.

MR. LEFLER: All of us are trying to get results with the least expense. I was thinking if perhaps you could control fineness from the standpoint of permeability only and get results that were good enough, it would be better from a cost standpoint.

MR. DIETERT: I believe this might answer your question. You should make a fineness test every two weeks, or once a month, and then test the permeability daily. This will give you the most economical program. I know of some plants that are testing fineness only once a month and they are getting good control.

MEMBER: On this same question, the author states that the all facing practice is desirable because of the reduction in cost, inferring that it is considerably cheaper. You include that as a fact, do you?

MR. DIETERT: I would. In all foundries I can picture off-hand, I would say that would be the fact. It would not be necessary to make up special batches of facing and have the problem of carrying it to the molders in small quantities and then, after you have it there in a box, it is in the way. The molder has to make a separate and distinct operation of taking some facing and putting it over the pattern, while if all the sand was facing, he could pull a lever or dump the sand in the mold and he would have one operation. It does incur more sand control if you use the all facing method. I believe that the control is cheaper than the labor involved in preparing facing. I am speaking of production shops in particular.

MEMBER: Will not the use of an all facing sand make for much more gas in the foundry?

MR. DIETERT: Not very much. May I refer to Mr. Dierker's work on the temperature of sand in the mold? He shows that the heat travels through a mold rather slowly and the temperature of the backing sand will not rise above 212° F. as long as moisture is left in the sand. As you evaporate water to steam, it takes a considerable amount of heat. So the amount of sand that is actually raised to a temperature where the sea coal is decomposed is quite small, maybe ¾-in. from casting in the majority of cases, and on a continuous system, probably ¼-in. I do not think the amount of gas with the all-facing method presents any problem.

MEMBER: When you refer to facing sand, I assume you mean a sand with enough sea coal added so that the sand does not "burn on" the castings. But, do you not also mean a sand that probably has a higher green strength and possibly, therefore, a higher clay content and less permeability than the backing sand, particularly if that sand has been prepared in a muller of some kind? Or, if you have an all facing heap, where does the matter of strength and permeability figure in?

MR. DIETERT: With the all facing method, you really run your strength, permeability and moisture of all sand as if it was facing. What you really do is prepare all sand carefully and then no bad sand can ever get against your pattern. In other words, you eliminate that one human error. If you use backing sand, you may not get facing sand over the complete pattern.

H. DEANE[2]: Do you have any information as to any difficulty in holding the sharp edges when using synthetic sand and using hand ramming or squeezing?

MR. DIETERT: We did not make that comparison, but it might be figured out. For example, No. 1 was natural sand and was squeezed in a mold. No. 2 was synthetic sand and was squeezed in a mold. I do not believe you would find any difference. The sands were worked about equally in reference to method of molding.

MR. DEANE: We have tried that and in ramming we have had difficulties because the sand seems to flow away from under the rammer. With the coarser sands, using molding machines, synthetic sands seem to be satisfactory.

MR. DIETERT: Of those foundries reporting, very few used the hand ram. Most of them use some form of power squeeze or hand squeeze, jolt strip squeeze and jolt squeeze and jolt roll-overs. There were only two foundries that were using only hand molding. Four foundries used hand ramming and some form of machine molding. The majority of them used some mechanical means of ramming their molds. Two foundries that were using nothing but hand rams, used nothing but natural sand. That bears out your statement. Carrying it a little farther, foundries, where both hand and some form of mechanical ramming was used, used both natural and synthetic sands in a 50-50 relation. There are certain types of synthetic clay bonds that have a tendency to be spongy and they are apparently the ones you refer to, Mr. Deane. There are certain synthetic bonds that may be used with hand ramming.

MR. DEANE: On this classification of finish, everyone has a different idea as to what a smooth casting is and what it is not. If you are judging your own castings and they are rough, you are not going to tell anybody else. Another point, with malleable iron, it is different than with the gray iron. Most malleable plants depend upon two cleaning operations, one with white iron and one when annealed. When were these casting finishes judged, before or after annealing?

MR. DIETERT: It is impossible to tell from the questionnaire when they judged the finish of the casting, whether it was after the first or second cleaning.

MR. DEANE: Would not the percentage of scrap tell you more than finish? If you had the percentage of scrap rather than finish that would be an actual figure.

MR. DIETERT: We thought about that question and debated whether it would be of any value. I wonder how many would care to put that figure down? We did not want to ask any questions that might be embarrassing. The percentage of scrap would have been interesting, because the questionnaire on the finish of casting brought out a number of points. Namely, the fact that the majority or the average permeability of sand used for producing smooth castings was around 27 and for producing medium finish it was around 42.

[2] Deere & Co., Moline, Ill.

MEMBER: Does not the author believe the hardness of the mold is an important factor in the finish of a casting?

MR. DIETERT: Mold hardness affects the finish materially. Whether the mold was gated at the top, at the part, or at the bottom also has an effect. The height of the pattern has a great deal to do with finish as does the shape of the pattern. In pouring molds where the molten metal drops down the side of the drag, it burns on and has a tendency to scab. Flat work would be another condition that would not lend itself readily to a good finish. While the shape of the casting affects the finish, it would be next to impossible probably to classify the shape of castings that were actually cast in these foundries in reference to finish.

We can obtain a direct relation between the casting finish and the A.F.A. mold hardness. The higher the A.F.A. mold hardness figure the smoother the casting finish, providing you do not get gas seams and scabs or rat tails and buckles. Is this along your line of thought?

MEMBER: Yes, I thought one could make a good looking casting by making a mold as hard as possible without running into trouble.

MEMBER: I noticed in this paper the author called special attention to the fact that synthetic sands usually had less hardness and the sand remained on fewer screens in the fineness test. I would like to ask from which you would expect to get the better finish, a sand that was all on one screen, if that is possible, or a sand that was made up of from several screens, fines and coarse material, to give the same fineness as the one all on one screen?

MR. DIETERT: My opinion is that the sand composed only of one grain size would give the smoother finish. I know there are many who would not agree with that statement. If you take a sand with only one size of sand grain, you could run a much finer sand than if the sand consisted of a variety of grain sizes. To obtain a permeability of 20, the sand could be of 250 mesh fineness. If it consisted of about four sand grains sizes, the sand grains would have to be an average of approximately 110 fineness.

MEMBER: I know the tendency when we make a synthetic sand, is to make it a little coarser, if anything, than the sand we were using. Without the fine particles we nearly always have trouble with edges if we patch the mold. If the molder puts a little water on the patch, it goes into mud immediately. Some of our molders use kerosene and oil instead of water for that reason.

MR. DIETERT: I believe this thought should prove helpful. Fines have a higher flowability than coarse material. As you increase the fineness of your sand, the flowability increases and the party who takes out the fines is reducing his flowability. That is in line with your thought.

MEMBER: Mr. Dietert brought up one very interesting point to me and that is the small number of malleable foundries using mold washes. I wonder if there is some reason in the way of technical difficulty involved other than lower cost.

Might it not be expected that a wash would adhere better to a steel

type of sand than a malleable type of sand? Malleable foundry men might have run into that difficulty, that the use of sea coal is not nearly the perfect thing but is involved in some difficulty?

MR. DIETERT: I think the conditions, as set forth in your statement, hold true. Naturally, with a type of sand like steel sand, one would resort to facing, mold face washes, since they would naturally adhere better to the coarser sand particles.

A. M. FULTON[2]: Regarding the summary on page 343, samples with green compression less than 6.5 lb. recording—about what would be the average of the compression strength of those 11 members?

Another question! Would we assume that a sand that would have an excess of 25 per cent fines would be the dead line, or what would we expect in that question of fines?

One other point on this 27.7 per cent average permeability for smooth finish, could that be held as a pretty good limit to work to or minimum?

MR. DIETERT: Replying to the first question, it would take some time to obtain an average figure. I would say 4.8 lb. is an average.

MR. FULTON: Would that be a minimum that we should look for in average sand heaps?

MR. DIETERT: It would all depend upon the type of pattern you were running and also how the flasks were barred. If you were running a type of casting that had a lot of flat surfaces on it, 15 per cent fines would be a nice minimum to work to. But if it was a type of casting that does not have exposed flat surface areas of irregular contour, a low strength sand is desirable. You would run a higher strength for the castings that have more intricate shapes. For flat work, where you have to combat expansion and contraction, you would use a sand with low strength.

Now, as to the permeability. The permeability value of 27.7 is the average of the permeabilities for the foundries reporting smooth finish. That does not mean that you have to have a 27 permeability to obtain a smooth finish, but it means that foundries reporting smooth finish, used sand averaging 27 in permeability, a very good permeability for a group of castings for small squeezer plates working in the 12 x 14, 16 x 24 flask up to work that would be put on jolt roll-over, but not exceeding 50 lb., with metal line of around a quarter of an inch. As a rule, casting ¼-in. and thicker section castings which run up to 300 lb. in weight could be put in sand with permeability of 50.

I wish to refer to the graph in Fig. 5. The thickness of the casting and the average weight of castings are shown on the vertical scales. Draw a line between the average wall thickness and the average weight of castings made on a particular floor where this line crosses the heavy permeability line, go straight down and read the permeability.

Now in respect to samples containing more than 25 per cent fines.

[2] Northern Malleable Iron Co., St. Paul, Minn.

If you were making castings which had to be tested for water tightness on a hydraulic test, I could say definitely that you should not have more than 25 per cent fines. There are many types of castings that are made in sand that contains more than 25 per cent fines but it must not be flat work. Any castings that have flat surfaces on them or that have to be tested for water tightness should be made in sand with less than 25 per cent fines. I believe when you exceed that figure, you could be questioned as to why you have so much fines in your sand. You may have a good reason but it is not a very common value. It is not used very often in malleable iron foundries according to this paper for the sand samples submitted. Assuming that the majority of the foundries are right, the average number of fines should not exceed 18 per cent.

Founding of Aluminum Bronze

By J. E. Crown,* Washington, D. C.

Abstract

This paper has been contributed by the author at the request of the Nonferrous Division Advisory Committee to include it in a series of papers on the founding of various alloys. This paper deals with the aluminum bronzes, one of the most difficult of the nonferrous alloys to produce with reasonable losses. The author, discussing composition, melting practice, and molding methods, points out the close control necessary stressing heading, gating and chilling. Castings of intricate design, he states, should only be specified after consultation between designer and foundryman. Compositions and test figures are given.

1. Many valuable papers have been presented on aluminum bronze with extensive data on its characteristics, physical properties, and structure in which reference is frequently made regarding the importance of attention to details in its manufacture so that the maximum properties may be obtained and that a successful product may be cast. The purpose of this present paper is to amplify these details and describe methods of manufacture developed to overcome many of the problems first encountered when this alloy was manufactured.

2. Although the founding of aluminum bronze is in general the same as other non-ferrous alloys, yet it is the most sensitive of the bronzes, a fact which causes many failures and stresses the importance of the need of vigilance in the attention to details.

Composition

3. Aluminum bronze is classed as a copper-rich aluminum copper alloy and may contain small percentages of other alloys to modify its properties. The majority of production is confined to copper-aluminum composition containing from 5 to 11 per cent

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Note: This paper was presented at a session on Non-Ferrous Castings at the 1936 Convention of A. F. A. in Detroit, Mich.

aluminum or copper-aluminum-iron containing from 5 to 10 per cent aluminum and 1 to 5 per cent iron.

4. The composition used by the United States Navy for Ordnance castings consists of 88 per cent copper, 9 per cent aluminum, 3 per cent iron, and is melted in natural draft crucible furnaces.

MELTING PRACTICE

Using All New Metal

5. When using all new metal, the copper is melted down under a good layer of charcoal and then deoxidized by small successive quantities of carbon-free manganese until small test buttons show a good shrinkage and then about one-half of the aluminum is added, which further acts as a deoxidizer and prepares the copper for the iron. The iron is now added in the form of thin sand-blasted strips of sheet steel and after thorough stirring, the remaining aluminum is added. To the complete melt, 0.5 per cent magnesium and manganese sulphate is added as a flux.

Scrap Use

6. When scrap is used in conjunction with new metal, the scrap is melted first, to which is added the aluminum, then the iron and finally the copper which has been preheated and fluxed in proportion to new metal charge.

7. Scrap should be confined to aluminum bronze scrap of previous melts as scrap copper or scrap aluminum, unless composition is definitely known, should not be used due to possible introduction of impurities.

Rapid Melting

8. Although melting should be at a low temperature, yet the melt should be completed as rapidly as practical to prevent undue exposure to furnace gases. Crucibles used for melting aluminum bronze should not be used for melting other alloys.

9. Charcoal used for covering must be clean and care taken to prevent metal from being contaminated by fuel used for melting.

POURING

10. For best results, it is better to pig the initial melt and remelt pigs when required. The ladle used for pigging should

not be used for other alloys and must be thoroughly dry, as any disturbance of the metal caused by the ladle may prove disastrous.

Molding

11. Normal sequence lists molding to follow melting and pouring, but in relative importance it would possibly be listed later, greater importance being placed on other factors to be discussed later, such as design, gating, heading and chilling which should be planned before molding is started.

12. Aluminum bronze is not hard on a mold, and regular brass founding practice is followed except that again the importance of attention to apparent minor details must be stressed.

Sand

13. Large castings are made in dry sand, using a coarse sand suitable for heavy brass. Medium and light castings are made in green sand where a good grade of Albany sand is satisfactory. Skin drying reduces risk of failure in green sand molding.

14. Where a binder is used, either in the molding sand or in the core, this should be checked closely to determine if it causes any "fluttering" of the metal against the face of the sand, for such agitation will cause porosity under the skin that will develop upon machining.

Heading and Gating

15. Aluminum bronze is a high shrinkage alloy and liberal use of heads is necessary. The copper-aluminum series requires heads about equal to manganese bronze, the copper-aluminum-iron series even greater. On heavy gears, circumferential heads often have proved very satisfactory in not only taking care of the shrinkage but also to furnish an outlet for the scurf created in pouring. Such a head is illustrated in Fig. 1, at A.

16. Gating is of the utmost importance as the type of gate selected often determines difference between success and failure.

17. This entire group of alloys is susceptible to the easy formation of dross and may be likened to soapy water in that the more it is agitated the more "suds" (scurf) is formed. A gate should be so designed that it allows quiet, easy, entrance of the metal into the mold and wherever possible so located that it can have a good flow before being interrupted by cores or protruding sections of the mold.

18. A variation in the use of the horn gate in which the

horn is reversed from usual practice has been very satisfactory. An illustration of this type of gate is shown in Fig. 1, at B. In the use of this gate, the large end of the horn is placed on the casting the small end connecting the down gate, the result being a reduction in the pressure of the metal and a quiet flow of metal at the outlet.

19. When pouring, the ladle should be held as close to the sprue or basin as possible and a steady stream maintained to prevent formation of dross and the entrapping of air.

CHILLING

20. There is no factor entering into the making of aluminum bronze castings of greater importance than the intelligent use of chills.

21. Chills are used for three major reasons: (1) To permit the production of difficult castings by the control of shrinkage in areas inaccessible to proper feeding; (2) improvement in physical properties at predetermined points; (3) control of scurf.

22. Controlling scurf by use of chills is possible, due to a peculiar phenomena in this alloy in that the scurf collects on the surface of the metal adjacent to a chill as if it were attracted to it and can therefore be subsequently removed by machining or grinding, thus leaving good clean metal under the surface.

23. There have been numerous instances of gear blanks having developed defective teeth, notwithstanding liberal heading having been practiced, that were changed into excellent castings by placing a chill around the tooth area in addition to regular heading, as illustrated by the arrangement of chills shown in A of Fig. 1.

24. The placing of intermittent chills with small sand areas interposed has proven in many instances more satisfactory than continuous chills.

DESIGN

25. The designer is attracted to this alloy by its physical properties, but for intelligent application, he should be familiar with its characteristics and founding peculiarities to determine if his design will permit proper feeding or chilling of remote areas to prevent weak spots and provide for machining of certain areas for clean surface conditions.

26. In general, design followed in producing manganese bronze castings can be followed in aluminum bronze.

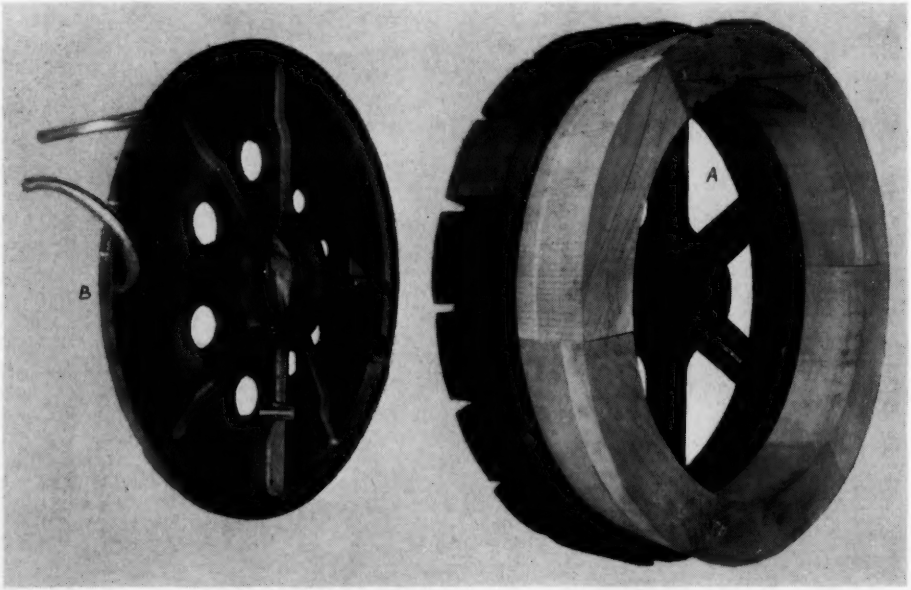

Fig. 1—(*A*) Pattern Equipment for Gear, Showing Circumferential Head and Chills in Position Around Tooth Area. (*B*) Inverted Horn Type of Gating.

FORGING INGOTS

27. As this alloy is readily forgeable, there is a demand for ingots of suitable design for forging billets. There is apparently no limit to the size of ingot that can be cast as ingots weighing 6-tons have been made with no indication that large ingots would introduce any new problem. Such an ingot is shown in Fig. 2A.

28. The design of the mold however is important, and the usual steel practice for large end up ingots should be followed. A tapered ingot, cast in an iron mold properly proportioned to give a greater chilling area at the bottom than at the top to permit uniform solidification from bottom to top of ingot, produces a clean, sound ingot, free from included scurf, with no secondary pipe, and yielding a high percentage of usable metal.

29. Fig. 2B shows a 10 in. diameter ingot, that measures 10 in. in diameter at the bottom, 11¾ in. at the top, and is 48 in. long, that is cast in an iron mold, 23 in. diameter at bottom, 22 in. diameter at the top, 54 in. long with a sand hot top, which gives a remarkable yield as indicated by depth of shrinkage as shown at the extreme left of the head of the ingot, C of Fig. 2.

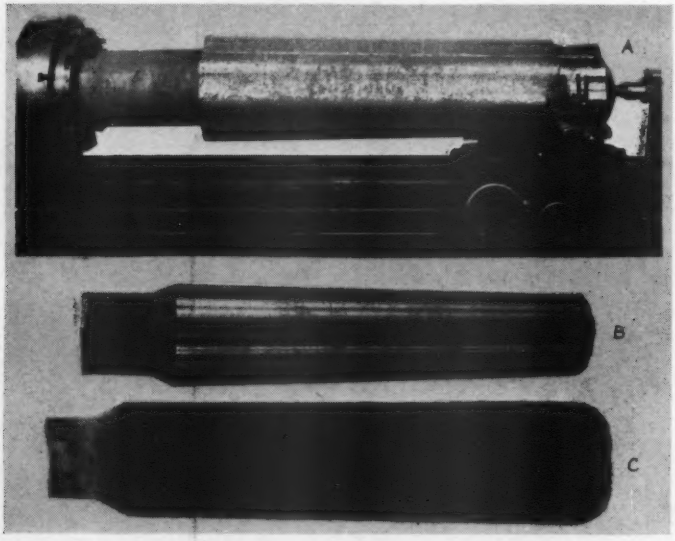

FIG. 2—(*A*) MACHINING EXTERIOR SURFACE OF 6-TON CORRUGATED ALUMINUM BRONZE FORGING INGOT. (*B*) FORGING INGOT, 10 IN. DIAMETER, SHOWING HOT TOP. (*C*) FORGING INGOT, 10 IN. DIAMETER, SPLIT HORIZONTALLY TO SHOW DEPTH OF SHRINKAGE. NOTE EXTREME LEFT OF INGOT HEAD.

Table 1

COMPOSITION AND PHYSICAL PROPERTIES—ALUMINUM BRONZES

Nominal Composition Cu. %	Al. %	Fe. %	Minimum Tensile Strength, lb. per sq. in.	Minimum Elongation in 2 in. per cent	Condition
88	9	3	65,000	20	Cast or wrought
90	10	..	65,000	20	Cast or wrought
89	10	1	80,000	5	Cast or wrought, heat treated

Table 2

AVERAGE TEST VALUES—ALUMINUM BRONZES[1]

Composition Cu.	Al.	Fe.	Condition	Physical Properties: Proportional Limit lb./sq. in.	Yield Point lb./sq. in.	Ult. Strength lb./sq. in.	Per Cent Elongation in 2 in.	Per Cent Reduction Area	Brinell Hardness	Izod. Impact (ft. lb.)*
90	10	..	Sand Cast	11,000	25,000	72,000	22	22	95	22
90	10	..	Cast & H.T.*	27,000	48,000	90,000	8	10	175	..
90	10	..	Forged & H.T.*	35,000	53,000	95,000	6	10	190	14
89	10	1	Sand Cast	12,000	27,000	74,000	24	24	95	25
89	10	1	Cast & H.T.*	31,000	54,000	90,000	10	12	175	..
86	10	4	Sand Cast	17,000	32,000	81,000	18	18	..	..
86	10	4	Cast & H.T.*	35,000	58,000	98,000	10	12	..	..
86	10	4	Forged & H.T.*	47,000	70,000	103,000	8	12	210	10
88	9	3	Sand Cast	17,000	31,000	77,000	44	36	110	25
88	9	3	Chill Cast	17,000	31,000	79,000	48	40	110	45
88	9	3	Cast & H.T.**	24,000	40,000	84,000	30	25	125	38
88	9	3	Forged	18,000	33,000	85,000	42	47	130	35
88	9	3	Forged & H.T.**	26,000	50,000	88,000	32	30	135	30

* Sections about 1½ in.

** Sections about ¾ in.

(a) Mesnager notch 2 mm. dia., 2 mm. deep.

[1] Strauss, J., *"Aluminum Bronze,"* TRANSACTIONS, American Society Steel Treating, vol. 12, p. 225, 1927.

FIELDS OF APPLICATION AND PROPERTIES

30. The high strength of this alloy, combined with moderate yet safe ductility, its low coefficient of friction when used in conjunction with steel, and its stability when in contact with many corroding agents are the principal reasons for its selection. The 88-9-3 alloy is probably used more than any of the other aluminum bronze compositions and has been selected for submarine gun mount parts, aircraft construction, and for worm wheels, propellers, and similar highly stressed parts. Table 1 shows compositions and physical properties.

31. Likewise in the manufacture of rolled or forged products requiring great strength and where subjected to corrosive action, such as valve stems, propeller blade bolts, pump and condenser bolts, excellent results have been obtained.

32. The 90-10 is used where the added hardness due to the iron is not required and yet a material with high strength, toughness, and good corrosion resistance properties is desired.

33. The 89-10-1 is specified where a heat treated alloy with strength, resistance to wear, pressure, or repeated shocks is required. Table 2 shows average test values obtained on aluminum bronzes.

CONCLUSION

34. As indicated by the precautions necessary to follow and the sensitiveness of this alloy to neglect of minor details, it is one of the most difficult of the non-ferrous alloys to produce consistently with reasonable losses and requires close supervision, metallurgical control, and therefore, castings of intricate design with uniform cross sections should only be specified after consultation between designer and foundryman.

DISCUSSION

In absence of the author, this paper was presented by J. E. Bush, an associate of the author and foreman, Naval Gun Factory, Washington, D. C.

J. E. RIFFER[1]: Will Mr. Bush go into detail on the question of chilling?

J. E. BUSH[2]: You are evidently familiar with why we chill castings —to equalize solidification. If we have a 2-in. section with a heavy projection, we make a chill to equalize the cross section, if it is impossible to get a head on the heavy area. Of course, wherever possible, we put heads on.

MR. RIFFER: The reason I ask that question is that we had an experience on a job recently on which there was a heavy cross section and we could not get any heads on. We put the chills in and it worked out wonderfully. However, we had an engineer from a plant and he insisted in putting the chill completely around, and I could not see where the benefit was derived. It was all machined off afterward. It was chilled at the bottom, but wherever there was a heavy cross section and we could not get a riser on, we would put the chills in these corners and overcome any checking whatever.

MR. BUSH: That pattern with the chills, shown in the paper, happens to be a pattern, somewhere near 30-in. in diameter. It was a gear and we put chills all around the outside. We tried to make the casting without chills, and after losing several of them, we came to our senses and tried the chills. Since that time, we have been very fortunate.

MR. RIFFER: The point I was trying to make was, in our case, where we wanted to use the chills around the pattern, the engineers insisted on having the chills on the drag side instead of on the outside where the teeth would be cut in. I could not see the advantage of this method.

CHAIRMAN T. E. KIHLGREN[3]: I think one thing might be pointed out in connection with aluminum bronzes, and that is that, in contrast to the tin bronzes, they freeze over a very narrow range, and it explains to a considerable extent the need for control of solidification by the use of chills. Aluminum bronze would behave somewhat similarly to pure metal as far as shrinkage is concerned, and where a heavy section is adjacent to a light section, the chill against the heavy section will hasten the freezing rate of the metal in that section and bring it a little bit nearer to that of the lighter section.

SAM TOUR[4]: On page 2 in paragraph 5 of the paper, the author describes "Melting Practice." While this description of deoxidizing the copper first with successive additions of carbon-free manganese might be a true description of the practice followed by the author, I do not believe it should be taken as a recommended practice for use all over the

[1] Manager, St. Catherines Brass, Ltd., St. Catherines, Ont., Canada.
[2] Foreman, Naval Gun Factory, Washington, D. C.
[3] Research Metallurgist, International Nickel Co., Bayonne, N. J.
[4] Vice-President, Lucius Pitkin, Inc., New York City.

country. I doubt whether this practice is followed in very many foundries. The use of carbon-free manganese to reduce copper to which aluminum is to be added, aluminum being such a powerful deoxidizer in itself, would seem to be an expensive procedure.

In the same paragraph, the author states "iron is now added in the form of thin sand-blasted strips of sheet steel." No mention is made of whether the steel should be high or low in carbon content. In the previous sentence "carbon-free manganese" was specified. If carbon is objectionable in manganese, then presumably it would also be objectionable in steel.

The author refers to a flux which is rather uncommon in the foundry industry, magnesium and manganese sulphate. I doubt that this flux is extensively used throughout the country.

Paragraph 7 states "Scrap should be confined to aluminum bronze scrap of previous melts as scrap copper or scrap aluminum, unless composition is definitely known, should not be used due to possible introduction of impurities." What impurities are harmful that one might find in copper or aluminum scrap? Is it silicon? Is it tin? I do not mean to advocate the use of scrap, but I do mean that when we lay down a blanket rejection of some material, we should certainly give some reasons why. If there are certain harmful impurities, we should know what they are and place limits on them.

In paragraph 22 of the paper, in connection with chills, the author's observations with regard to the scurf being attracted by the chills and being thereby, by some mysterious power, withdrawn out of the body of the casting is certainly an interesting observation, but I doubt its accuracy. It might be that scurf forms near a chill, but that a chill draws scurf from elsewhere and concentrates it in one place is difficult to believe.

MR. BUSH: In replying to Mr. Tour on the chilling effect, before Mr. Crown wrote the paper, one casting of the job shown in the paper was made without chills and the casting was sawed into a number of pieces. Then later we put the chills around the pattern and made another casting for the specific purpose of seeing where the scurf was. The result was that anyone with foundry practice, or foundry knowledge, could take the two sets of metal pieces and lay them together properly without looking at the exterior. One could see which set had had the chills on, because the scurf was approximately 1/4-in. deep on the surface of the one without the chill and the other one had very little.

However, we did not go far enough with that comparison. If we had had more time, we would have machined them to find the effects on machining of putting chills on any of the surfaces like these.

In regard to the scrap that Mr. Crown is referring to, I know he did not have in mind any scrap that you might go out into the yard and gather up, or something to that effect. What he was speaking about is returned scrap from the shed.

O. W. ELLIS[5]: The practice of adding magnesium and manganese sulphate to aluminum bronze as a flux is, of course, quite well known. I think that in the gun factory such a flux has been used for the past 15 years.

[5] Ontario Research Foundation, Toronto, Ontario, Canada.

There is a certain looseness in the description of the flux in this paper. It says: "0.5 per cent magnesium and manganese sulphate is added as a flux." I think it might be worth while to state exactly what percentage of each is used. It does not state clearly whether it is a half per cent of each, whether it is 0.4 of one and 0.1 per cent of the other, and so on.

MR. BUSH: I am very sorry that I cannot give these percentages, but I would like to refer you to the article written by Mr. Strauss, which will explain this flux thoroughly.

MEMBER: Paragraph 13 mentions that large castings are made in dry sand and medium and light castings are made in green sand. I would like to know more about the ranges of sizes in these classifications.

Then paragraph 14 mentions "fluttering." What types of binders have had a tendency to cause fluttering and what types of binders are recommended.

MR. BUSH: In regard to the binders, at present we are using a cereal binder which has been very successful on our green sand aluminum bronze. On our dry sand, we do not use that type binder.

In regard to the other question, in green sand, the casting average from 2 to 150 lb. If they go over that, we generally go around a little with the torch, and if they go up as high as 1200 to 1500 lb., of which there are a lot of them, we put them in the oven.

MR. ELLIS: I would like to ask another question regarding the pouring of ingots. It is clear that the author has in mind the necessity for avoiding the agitation of this alloy during pouring; he goes so far as to suggest, for example, that even the "fluttering" that can occur in sand molds may cause trouble. The ingots for forgings apparently are 54 in. long. It seems to me that there is considerable opportunity for agitation of the metal when the drop into the mold must be at least 54 in.

I know that in some quarters, with chill castings of this type, what is known as the Durville process has been employed. That is a process in which the ingot mold and the crucible are placed upon a revolving platform which can be rotated in such a way as to pass the metal into the mold with as little agitation as possible. This process has been used in Europe very generally for flat ingots. I was wondering whether there is any necessity for such care in the making of flat ingots if in making large circular ingots it was quite satisfactory to employ the methods described in this paper.

MR. BUSH: We have made ingots up to 6 tons, and we use the 54 in. mold. This ingot casting is actually about 64 in. long because it has a 10 in. hot pot on top, which makes it 10 in. further for the metal to drop. We found very little trouble with that. We melt the metal in the pit furnace and put it in the ladle and use the bottom pour, the same as in steel casting or steel ingot practice.

I would like to know if there is anyone here who has adopted the practice of the use of the horn gate by inverting it and using the large end on the casting instead of the small end. I would like to say that if you have not, if you are going to make aluminum or manganese bronze,

I wish you would try those things and see if you get as much benefit out of it as we did.

MEMBER: Mr. Bush, have you had any experience in using a goose-neck gate and placing the mold uphill, letting the metal run uphill, for the prevention of your dross and scurf? It has worked very successfully.

MR. BUSH: No, we have never tried it on aluminum bronze, but we have tried it on other metals.

MEMBER: In these sessions, the use of charcoal has been mentioned. One advised its use and someone else advised against it. Mr. Bush, what was your experience in the use or non-use of charcoal?

MR. BUSH: We use charcoal. It is an adopted practice, covering the top of the metal.

HAROLD J. ROAST[6]: I find it hard to believe that Mr. Bush cannot get someone to admit using the horn gate in the right way. I have often wondered why people use it the wrong way, particularly for metals that should not be agitated, but I was told in the foundry that it is difficult to get the horn gate out. I submit that if that is the only trouble, the cleverness of the average foundryman would soon overcome that difficulty.

MR. BUSH: Our trouble was to get our molders to agree with our idea as to this method of using a horn gate.

MEMBER: In a number of gating operations, it is difficult to place the gate on in that manner, and I think that is an objection that stands in the way of a good many applications.

D. F. O'CONNOR[7]: In connection with the use of horn gates, when making pressure castings some years ago, I had some experience with the particular horn gate described here. I do not believe we reversed the gate at that time; but it occurred to me that by using these horn gates there was possibility of increasing the soundness in pressure castings and reduce the friction of the metal against the molding sand, producing a cleaner casting on the surface.

Keeping this theory in mind, I tried out what they called a strainer gate. (Some of you, no doubt, are familiar with it because there are some on exhibition here.) At that time I did not know that any were in use. The thought just simply came to me we should resist as much as possible the pressure in pouring so that we might produce a casting which would have a fairly good finish on the surface and at the same time be sound.

So to get away from the horn gate and obtain the same effect in production, we adopted the strainer core. At the present time, it is working out very well as far as soundness is concerned, and we have very good results with it both in our 85-5-5-5 and Composition "M" metals which must meet Navy Specifications.

I do not believe the horn gate can be eliminated entirely; but for production purposes a strainer core will give the same results.

MEMBER: I might say that we employ that strainer-core skim gate and it is the finest gate I have ever used on manganese bronze or any

[6] Vice President, Canadian Bronze Co., Montreal, P. Q., Canada.
[7] Foreman, Walworth Co., Boston, Mass.

drossy metal. I have been using it now for 2 or 3 months, just as the same as they use for cylinders in crank cases that the automobile people use.

MR. BUSH: We have never used the strainer core on either the manganese or the aluminum bronze, and while not doubting its effectiveness, I would hate to change the practice of using the horn gate when we have met with the success that we have.

MR. RIFFER: In my plant, at times, we get in a lot of patterns from the malleable shop and they all use the strainer, with the result, the way their patterns are equipped, that it is necessary for us to use their strainer gate. But when we make up patterns ourselves, we use the horn gate wherever possible, and as a previous speaker here mentioned, we reverse it and use the large end, because that is the point where we use the heavy riser on top, so that the metal flows in freely. There is no agitation and no squirt or nozzle to it. We have our gate run across into the small point, and we have had wonderful success. We have made such castings with weights up to 150 lb. with high copper content for engineers of the electric power companies, who are very exacting. If there is one speck of dirt that you can see with the magnifying glass, we get the casting back.

We have absolutely no agitation, and our discount is nil. Prior to using that horn gate we had a discount of approximately 5 per cent scrap castings.

CHAIRMAN KIHLGREN: It seems to me that we are dealing with three bronzes which are certainly far apart in many characteristics when we are dealing with manganese bronze, aluminum bronze, and silicon bronze. Yet there are, nevertheless, certain things that are common to all of them. I note, in looking at these papers and listening to the discussion, that there is pretty complete agreement that reducing conditions or a reducing atmosphere are undesirable in melting. A slightly oxidizing furnace atmosphere seems to be quite generally recommended by the authors of the papers. I think it is recognized that in the copper alloys, hydrogen is quite objectionable and is prone to yield difficulty with interdendritic shrinkage. Hydrogen is readily soluble and may be liberated in a considerable quantity if it is present at the time the mixture is beginning to freeze, giving rise to incipient or interdendritic shrinkage. The use of an oxidizing melting atmosphere, and even deliberate oxidation of the melt is helpful in eliminating hydrogen.

Another thing that seems to me is quite apparent in all three bronzes is that even though the melting procedure be correct, all the precautions observed in melting may be nullified if the molding procedure is unsatisfactory. In addition to the avoidance of turbulence by recourse to such expedients as the inverted horn gate, the proper location of the risers is particularly important. Unless the risers are so located that they can receive hot metal to feed the casting, they may not only be useless but actually harmful.

H. M. ST. JOHN[8]: My experience does not qualify me to discuss methods of gating in connection with these alloys, but none of the mem-

[8] Metallurgist, Detroit Lubricator Co., Detroit, Mich.

bers has spoken of strainer cores in connection with brass, and I would simply like to recommend to those of you who have not tried it and have brass castings of rather ordinary small size to be made, to try a strainer core. We have been using them for 10 or 12 years, and I do not know just how we would get along without them.

J. E. CROWN (*Submitted as Written Closure*): Mr. Tour is correct in his comments on the use of carbon free manganese as a deoxidizer as this was a description of Naval Gun Factory practice and does not represent general commercial practice. In this description, the paper should have stated that the steel used for iron additions has a very low carbon content rarely exceeding 0.15 per cent.

Referring to undesirable use of scrap copper and aluminum of unknown origin, the term "impurities" was loosely used as the intent of the author was to avoid introduction of foreign materials from scrap which may be alloys containing other elements instead of being solely copper or aluminum.

The author is unable to account for the elimination of deep seated dross on a given surface by the use of a chill causing its concentration on the surface but in practice in innumerable instances, especially on gear blanks, that is exactly what happens.

Mr. Ellis answered the question relative to flux. The percentage should be 0.05 per cent using 1 part magnesium to 4 parts manganese sulphate.

The Heat Treatment of Cast Iron By Hardening and Tempering*

By J. E. Hurst**, Litchfield, Staffordshire, England

Abstract

The author points out in this paper that one of the outstanding developments in cast iron metallurgy is the hardening and tempering of that material. He also states that although the effect of hardening on cast iron was known as early as 1839, the effect of tempering in improving the properties is a modern development and is due to research and investigation. He discusses the effect of hardening and tempering on the mechanical properties, the effect of casting condition and composition on properties obtainable, the effect of hardening and tempering on the stress-strain diagram and on the modulus of elasticity. The second section of the paper is devoted to a discussion of the mechanism of hardening and tempering and discusses such points as the effect of carbon, carbon plus silicon, quenching temperatures. The next section deals with the influence of chemical composition and alloy additions, their effect on the depth of hardening, the stabilizing effect of molybdenum on the strength of nitrogen-hardening cast iron and on alloy's effect on quenching speed. The last section of the paper explains the effect of hardening and tempering on internal stresses.

1. *"To harden cast iron. Heat the article to a bright red heat, and quench in a mixture of 3 gallons of water, ½ pint of oil of vitriol and 2 oz. of saltpetre. Another mixture for quenching consists of salt water, 10 gallons, salt 1 peck, oil of vitriol ½ pint, saltpetre ½ lb., prussiate of potash ¼ lb., cyanide of potash ½ lb., by repeating the process cast iron may be made harder."* (Quotation "Works' Managers Handbook," Walter S. Hutton, 1901.)

* This paper is the official exchange paper of the Institute of British Foundrymen for the 1936 Convention of the American Foundrymen's Association.

** President of the Institute of British Foundrymen and Technical Director, Sheepbridge Stokes Centrifugal Castings Co., Ltd., Chesterfield and Bradley and Foster, Ltd., Darleston, England.

Note: This paper was presented at a session on Cast Iron at the 1936 Convention of A. F. A. in Detroit, Mich.

2. One of the many outstanding developments in the metallurgy of cast iron, which have occurred during recent years, is its heat treatment by hardening and tempering. As a means of obtaining hardened cast iron wearing parts for machinery, heat treatment by hardening and tempering is now practiced extensively and it is now fully understood that such treatments can be applied without the risk of any deterioration in the mechanical properties. It is this knowledge, arising out of recent research and investigations, upon which the claim rests for hardening and tempering cast iron as a modern development in the field of the metallurgy of cast iron.

3. Quotations from practical workshop handbooks, of which the one used as a text to this paper is typical, show that attention has been given to the hardening of cast iron by quenching for a long time. The British patent records contain references to the hardening of cast iron. An early one, dating back to the year 1839, recommended that cast iron be heated to a blood red heat and quenched in water containing green vitriol or alternatively alum, saltpetre and prussiate of potash. It is of some general interest to record that the majority of these early references apparently attach great importance to the quenching media and a wide variety of different types of solutions embodying different salts, mixtures of salts and acids have been recommended.

4. It is clear from modern research work that all these old processes would be successful perhaps in securing increased hardness. However, as none of these old mixtures appears to embody tempering treatments subsequent to hardening, it is to be presumed that the important effect of tempering in restoring the strength properties, which are impaired by the quench hardening treatment, was unknown.

THE EFFECT OF HARDENING AND TEMPERING ON MECHANICAL STRENGTH PROPERTIES

5. This knowledge of the influence of suitable tempering treatments applied to cast iron in the quench-hardened condition in restoring and even improving the mechanical strength properties, appears to be due entirely to modern research work, principally the writer's own investigations[1].

[1] Superior numbers refer to the references at the end of this paper.

Effect of Hardening on Strength.

6. The results of these investigations show that, when cast iron is subjected to hardening treatment by heating to temperatures above the A_3 critical point, and quenched in a suitable media, either water or oil, an increase in hardness accompanied by a marked drop in ultimate breaking strength, either in tension, compression, shear or transverse loading, results. The magnitude of the increase in hardness varies of course with the chemical composition and the structural condition of the particular cast iron

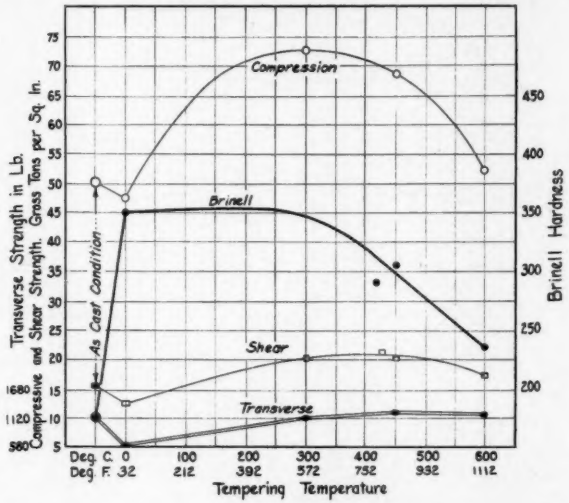
Compression
Brinell
Shear
Transverse
As Cast Condition
Transverse Strength in Lb. Compressive and Shear Strength. Gross Tons per Sq. In.
Brinell Hardness
Deg. C. 0 100 200 300 400 500 600
Deg. F. 32 212 392 572 752 932 1112
Tempering Temperature

FIG. 1—EFFECT OF HARDENING AND TEMPERING ON STRENGTH PROPERTIES (GUILLET).

treated; but the increment in hardness may be over 100 per cent greater than the original "as cast" condition. In a like manner, the magnitude of the decrease in ultimate breaking strength varies according to particular conditions, but it can be of a very serious order and reductions of over 50 per cent in the ultimate strength value under conditions of transverse bending have been observed in quenched specimens.

Effect of Tempering on Strength.

7. Tempering the quench-hardened specimens is accompanied by a recovery in the ultimate breaking strength value and all the investigations show that this recovery increases uniformly with

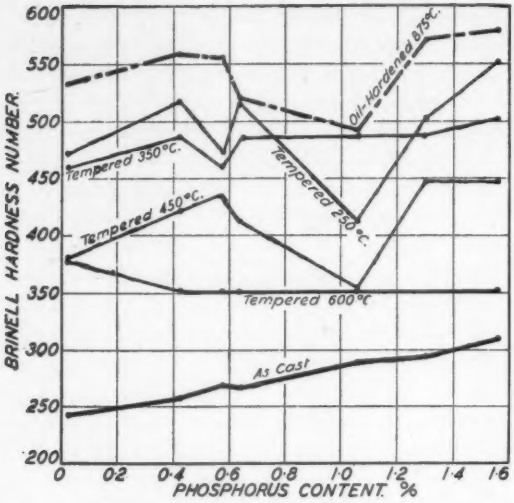

FIG. 2—BRINELL HARDNESS OF HARDENED AND TEMPERED SPECIMENS OF VARYING PHOSPHORUS CONTENTS.

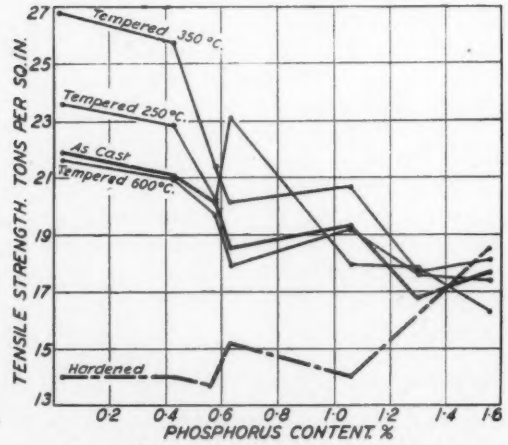

FIG. 3—TENSILE STRENGTH OF HARDENED AND TEMPERED SPECIMENS OF VARYING PHOSPHORUS CONTENTS.

increasing temperature until a maximum is reached followed by a decline with still further increment in tempering temperature. This phenomenon is accompanied by a decrease in brinell hardness and the general effect of quench-hardening and tempering on the hardness value and strength properties is illustrated in Fig. 1.

Effect of Hardening Plus Tempering on Strength.

8. Some idea of the magnitude of the influence of hardening and tempering on the hardness and ultimate breaking strength values is obtained from Figs. 2 and 3. These embody the actual

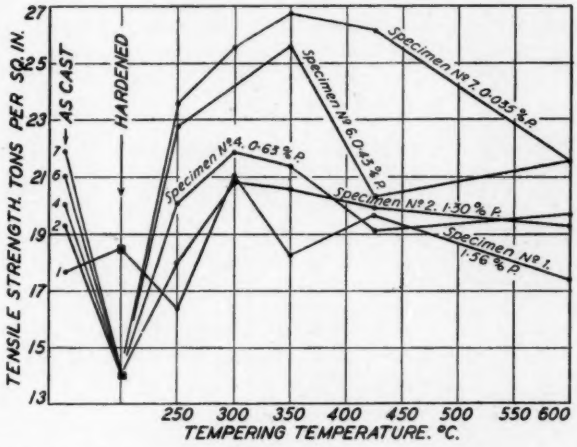

FIG. 4—TENSILE STRENGTH-TEMPERING TEMPERATURE RELATIONSHIP, AS CAST, HARDENED AND TEMPERED.

test results on a series of specimens of centrifugally-cast, chromium-alloy, cast irons containing varying amounts of phosphorus in accordance with the chemical analyses given in Table 1. Fuller details of the actual experimental procedure followed are to be obtained by reference to the original paper.[2]

9. The quench-hardening effect has been obtained by quenching the specimens in oil from a temperature of 875° C. (1607° F.) and it will be seen that in this condition, an increment in hardness of from 244 to 534, nearly 100 per cent, has been obtained in the low phosphorus specimen. In the case of ultimate breaking strength in the same specimen, an increment of nearly 23 per cent

from 21.9 to 26.8 tons per sq. in. (49,060 to 60,030 lb. per sq. in.) modulus of rupture stress was recorded.

10. In this connection, Fig. 4 shows the variation in strength results for these same specimens, plotted against the tempering temperature. The strength properties in the "as-cast" and hardened conditions included in the same diagram show the effect of the quench-hardening treatment in lowering the strength values and also the restoration of the strength after tempering, attaining a maximum value in excess of the original "as-cast" condition is clearly indicated. This improvement in the strength properties of cast iron in the hardened and tempered condition is the outstanding discovery arising out of recent research work and, in that it has led to the establishment of confidence in the strength properties of hardened and tempered cast irons, it has been of pre-

Table 1

ANALYSES OF SPECIMENS OF VARYING PHOSPHORUS CONTENTS

Spec. No.	T. C. %	C. C. %	Graphite. %	Silicon. %	Manganese. %	Phosphorus. %	Chromium. %
1	3.39	0.52	2.87	2.21	1.07	1.56	0.52
2	3.49	0.49	3.00	2.16	1.08	1.30	0.71
3	3.44	0.30	3.14	2.44	1.01	1.06	0.59
4	3.55	0.46	3.09	2.35	1.00	0.63	0.61
5	3.58	0.39	3.19	2.44	0.93	0.58	0.62
6	3.60	0.54	3.06	2.44	1.09	0.43	0.55
7	3.81	0.59	3.22	2.49	1.02	0.035	0.61

eminent importance in the commercial development of this method of hardening cast irons.

Condition and Analysis

11. Recently it has been shown[3] that the magnitude of maximum improvement in strength results due to hardening and tempering, is to an extent dependent upon the condition, whether sand cast or chill cast, and also upon the chemical composition particularly as regards the total carbon and silicon contents. The effect of these conditions is demonstrated by Figs. 5 and 6. The experimental work upon which these diagrams are based was carried out on a series of cast irons of the compositions shown in Table 2.

12. The specimens were quench-hardened in oil from a temperature of 850° C. (1562° F.) and tempered in the usual manner.

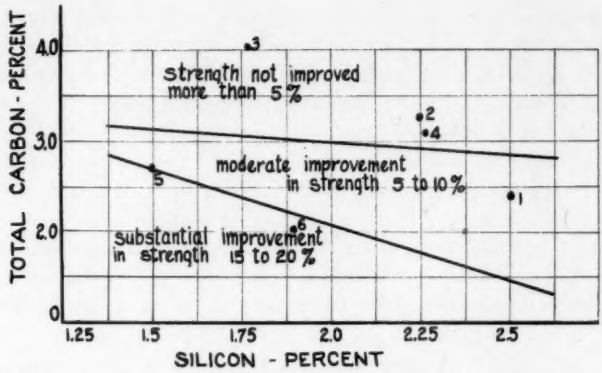

FIG. 5—RELATION BETWEEN CARBON AND SILICON CONTENTS AND IMPROVEMENT IN STRENGTH RESULTS DUE TO HARDENING AND TEMPERING (PIWOWARSKY).

Fig. 5 is divided into three zones and shows the relation between the total carbon and silicon contents in sand cast material which yield improvements in strength properties of something less than 5 per cent (zone 1), 5 to 10 per cent (zone 2) and over 10 up to 20 per cent (zone 3). Fig. 6 is of particular interest in that, in addition to showing the limit of total carbon plus silicon contents

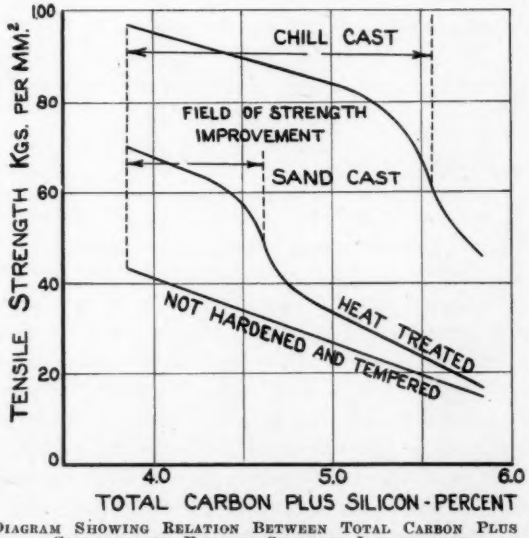

FIG. 6—DIAGRAM SHOWING RELATION BETWEEN TOTAL CARBON PLUS SILICON—CONDITION AND FIELD OF STRENGTH IMPROVEMENT.

in both sand cast and chill cast material beyond which very small improvement in strength properties is obtained, it also shows the greater magnitude of increment in the strength properties in the chill cast material due to hardening and tempering. Even in the chill cast material there appears to exist a maximum of total carbon plus silicon contents, which is at a higher value than in the case of the sand cast specimens, beyond which there is a reduction in the magnitude of the improvement in strength results.

13. It is of importance to bear in mind that the test results given in connection with centrifugally-cast material throughout this paper are obtained on material cast in metal molds and as

Table 2

CHEMICAL COMPOSITION OF SPECIMENS (PIWOWARSKY)

No.	Total Carbon %	Graphite %	Combined Carbon %	Tot: C+ Si %	Manganese %	Sulphur %	Phosphorus %
1	2.40	1.46	0.94	4.9	0.28	0.070	0.040
2	3.28	2.80	0.48	5.5	0.43	0.019	0.062
3	4.08	3.40	0.68	5.8	0.54	0.020	0.066
5	2.70	0.92	1.78	4.2	....	.....	.....
6	2.04	traces	2.04	3.9	....	.....	.....
4*	3.12	2.60	0.52	5.4	0.39	0.020	0.062

*Also contained 1.77% Nickel and 0.53% Chromium.

such are to be regarded as coming within the category of chill cast material.

Stress-Strain Relationships

14. An important aspect of the strength properties is the study of the stress strain curves and some attention has been devoted to the influence of hardening and tempering upon the character of the stress strain relationships. In Figs. 7 and 8, the stress-deflection curves determined upon annular ring specimens are shown for the series of centrifugally-cast specimens detailed in Table 1. The curves in Fig. 7, taken from the specimens in the "as-cast" condition, are characteristic and show an increasing amount of plastic deformation with diminishing phosphorus content, as indicated by the curvature in the upper portion of the curves. Fig. 8 shows curves for the same specimens in the hardened and tempered condition, tempered at 350° C. (662° F.), the

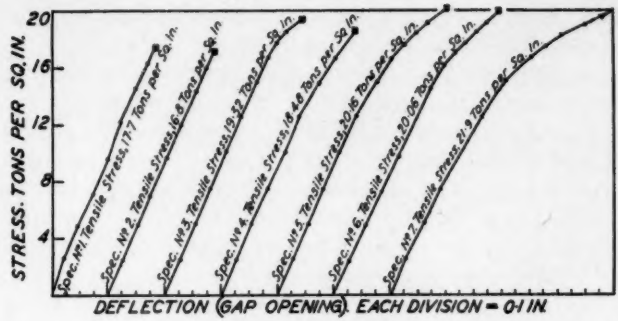
STRESS. TONS PER SQ. IN.
20
16
12
8
4
Spec. No 1. Tensile Stress, 17·7 Tons per Sq. In.
Spec. No 2. Tensile Stress, 16·8 Tons per Sq. In.
Spec. No 3. Tensile Stress, 19·52 Tons per Sq. In.
Spec. No 4. Tensile Stress, 18·48 Tons per Sq. In.
Spec. No 5. Tensile Stress, 20·18 Tons per Sq. In.
Spec. No 6. Tensile Stress, 20·06 Tons per Sq. In.
Spec. No 7. Tensile Stress, 21·9 Tons per Sq. In.
DEFLECTION (GAP OPENING). EACH DIVISION = 0·1 IN.

FIG. 7—STRESS-DEFLECTION CURVES, AS CAST.

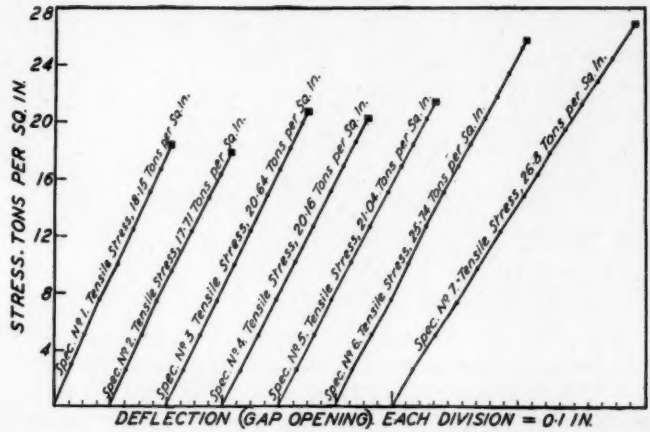
STRESS. TONS PER SQ. IN
28
24
20
16
12
8
4
Spec. No 1. Tensile Stress, 18·15 Tons per Sq. In.
Spec No 2. Tensile Stress, 17·71 Tons per Sq. In.
Spec. No 3. Tensile Stress, 20·64 Tons per Sq. In.
Spec. No 4. Tensile Stress, 20·16 Tons per Sq. In.
Spec. No 5. Tensile Stress, 21·04 Tons per Sq. In.
Spec. No 6. Tensile stress, 25·74 Tons per Sq. In.
Spec. No 7. Tensile Stress, 26·8 Tons per Sq. In.
DEFLECTION (GAP OPENING). EACH DIVISION = 0·1 IN.

FIG. 8—STRESS-DEFLECTION CURVES, HARDENED, AND TEMPERED AT 350° C. (662° F.)

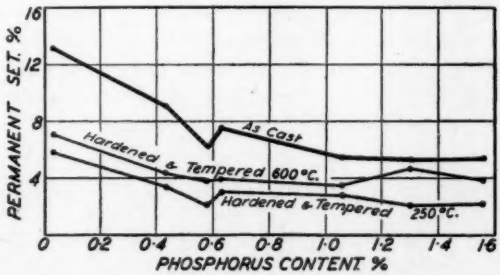

FIG. 9—PERMANENT SET, AS CAST, HARDENED, AND TEMPERED.

condition corresponding to the maximum increment in strength in the lower phosphorus members of the series.

15. One of the outstanding characteristics is the reduction in curvature and consequently the reduction in plastic deformation during the breaking. This is further exemplified by the reduction in permanent set value indicated in Fig. 9. This is apparently a characteristic effect of hardening and tempering cast iron and is an effect of some industrial importance (*e. g.* where cast iron is used as a spring in the case of piston rings and where it is subjected to the repeated applications of stress).

16. If the included areas of the stress-deflection curves are accepted as a measure of the resilience and as a comparative measure of the toughness as opposed to brittleness, these curves clearly indicate an increase in included area and consequently in toughness due to hardening and tempering. With increase in tempering temperature beyond that at which maximum strength properties are obtained, the curves tend to become more nearly as the original as-cast condition, but in general they rarely become identical. Even when the same hardness value after tempering as in the "as-cast" condition is reached, the material shows less permanent set and less plastic deformation characteristics, particularly in the lower phosphorus members of this series.

Effect on Modulus of Elasticity

17. The study of the modulus of elasticity (EN value) in the above specimens shows that in the "as-cast" condition, this value shows a marked and steady increase with increasing phosphorus contents. In the hardened and tempered conditions, an increase in the phosphorus is accompanied by an increase in the EN value, although the effect of these treatments is to lower the general level of the value. Tempering at the higher temperature is accompanied by a recovery of this property in the direction of the "as-cast" condition. The fall in value is the greatest in the lowest phosphorus specimens and an increase in phosphorus appears to minimize the reduction in value due to this cause.

THE MECHANISM OF HARDENING AND TEMPERING

18. The examination of quenched and tempered specimens under the microscope shows that, exactly as in the case of steels, the hardening effect is due to the formation of martensite and the

effect of tempering at successively higher temperatures is accompanied by a gradual change from martensitic to sorbitic structures. It is of some theoretical and general interest to note that the hardening effect in cast irons is not of necessity proportional to the amount of combined carbon present initially and that the hardening effect can be obtained in specimens in which, prior to the heat treatment, combined carbon is completely absent.

Effect of Combined Carbon

19. This was demonstrated first by the hardening and tempering of specimens in which the combined carbon initially present had been completely decomposed by a drastic annealing treatment. In some experiments of this nature,[4] the annealed specimens showing no combined carbon on analysis responded just as readily to the hardening and tempering treatments as did the specimens in the "as-cast" condition containing substantial amounts of combined carbon. Similarly, the series of specimens detailed in Table 1 responded to hardening and tempering after a preliminary drastic annealing treatment at 900° C. (1652° F.), although some irregularity in the extent of the hardening was noted, particularly in the high phosphorus content specimens.

20. An additional example is of interest. It is taken from the series of specimens whose chemical composition is given in Table 3. This again is a series of centrifugally-cast specimens of varying phosphorus contents and, in the low phosphorus specimen No. 1, the chemical analysis shows the complete absence of combined carbon. The hardness results in Table 4 show clearly that this specimen has hardened to even a greater degree than the specimens containing an initially higher combined carbon content. As a matter of fact, in this specimen, although the chemical analysis showed combined carbon to be completely absent, the micro-structure showed the presence of very slight traces of pearlite.

21. To make certain that hardening could take place in the complete absence of pearlite, specimens from the same castings were drastically annealed at 950° C. (1742° F.) for a total period of 16 hours heating and cooling, and even with the complete absence of initial pearlite, the specimens were found to respond to the hardening and tempering treatment. The microstructures are shown in Fig. 10. It would appear from results of this nature that the hardening effect may be brought about in part by the solution of the graphite.

Table 3

CHEMICAL ANALYSES OF CENTRIFUGALLY-CAST SPECIMENS OF VARYING PHOSPHORUS CONTENTS AND FINE GRAPHITE STRUCTURES.

Sample No.	Total Carbon Per Cent	Graphite Per Cent	Combined Carbon Per Cent	Silicon Per Cent	Manganese Per Cent	Phosphorus Per Cent
1	3.49	3.49	Nil.	2.49	0.55	0.022
2	3.47	3.28	0.19	2.49	0.59	0.526
3	3.52	3.03	0.49	2.63	0.41	0.560
4	3.49	2.79	0.70	2.58	0.63	0.660

Table 4

MECHANICAL PROPERTIES OF SPECIMENS AS DETAILED IN TABLE 3

Specimen No.	As Cast		OQ*875° C. (1427° F.) Temp.†275° C.(527° F.)		OQ*875° C. (1427° F.) Temp.†450° C.(842° F.)	
	Modulus of Rupture					
	Tons/in²	Lb./in²	Tons/in²	Lb./in²	Tons/in²	Lb./in²
1	22.8	51,070	48.20	107,970	44.50	99,680
2	27.2	60,930	42.50	95,200	43.50	97,440
3	28.0	62,720	41.25	92,400	43.30	96,990
4	23.2	51,970	37.30	83,550	36.20	81,090
	Modulus of Elasticity lb. per sq. in x 10^6					
1	16.1		15.50		14.10	
2	16.6		14.40		15.30	
3	17.5		16.90		16.10	
4	15.7		15.50		15.60	
	Permanent Set, Per Cent					
1	9.95		3.56		5.00	
2	21.7		7.70		5.00	
3	15.1		6.25		5.35	
4	22.2		5.85		4.70	
	Brinell Hardness					
1	163		474		412	
2	196		488		390	
3	207		412		380	
4	196		435		423	

* Oil-quenched.
† Tempered.

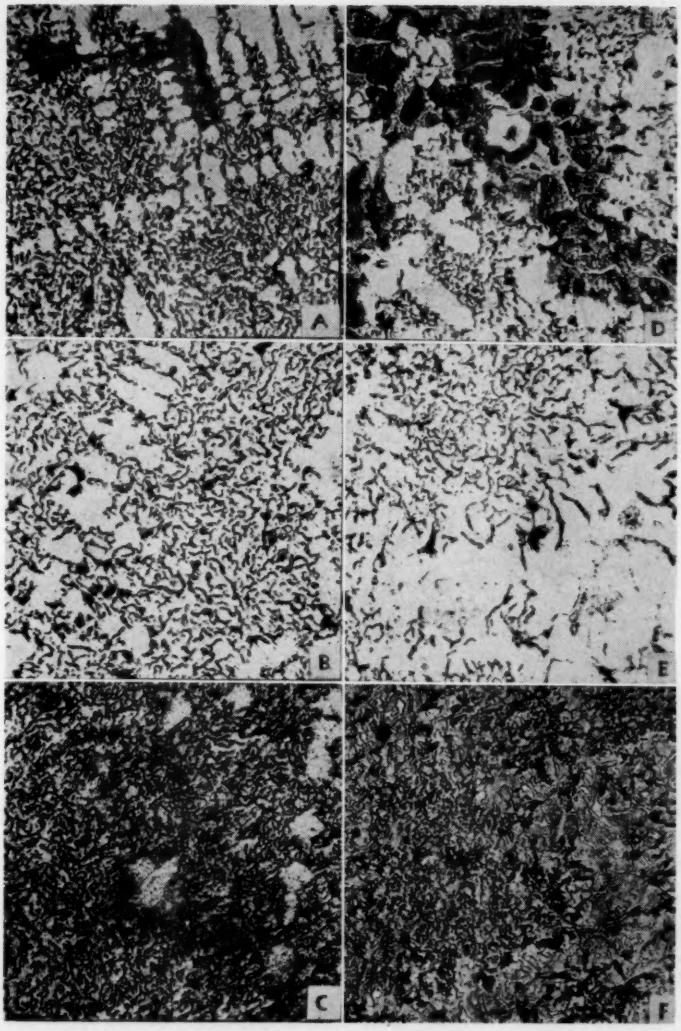

FIG. 10—STRUCTURES OF LOW PHOSPHORUS SPECIMEN NO. 1 ETCHED IN PICRIC ACID, 200X, (A) AS CAST, (B) ANNEALED, (C) HARDENED AND TEMPERED AT 275° C. (527° F.); HIGH PHOSPHORUS SPECIMEN NO. 4, ETCHED IN PICRIC ACID, 200X, (D) AS CAST, (E) ANNEALED (F) HARDENED AND TEMPERED AT 275° C. (527° F.).

22. It is known that on heating to temperatures of 900 to 950° C. (1652 to 1742° F.), some portion of the graphite can be redissolved and retained in the martensitic condition by quenching. This was shown by the author as far back as 1917[5] and it is clear that this effect must be taken into consideration in the formulation of any conception of the mechanism of quench-hardening in cast iron.

23. The results of this particular experiment, in Tables 3 and 4 and the illustration in Fig. 10, have been included with the additional object of drawing attention to the important effect of the condition of the graphite on the test results obtained. All these specimens, as indicated, were centrifugally-cast in metal molds and attention is drawn to the very marked improvement in the ultimate breaking strength results, due to the hardening and tempering amounting to, in the case of the low phosphorus specimen No. 1, well over 100 per cent. All these specimens, as will be seen from the illustrations, possessed structures of the ferrite-fine graphite type; in a well developed form in specimen No. 1 and diminishing somewhat in form and magnitude in the specimens with increasing phosphorus. It is impossible to resist the conclusion that these exceptional improvements in mechanical strength properties are associated with this structural condition of the graphite. Further investigations appear to confirm this view. It is of interest to draw attention to the apparent coarsening of the graphite in specimen No. 1, particularly as a result of the annealing treatment.

Carbon plus Silicon Contents

24. In passing, it is worth while drawing attention to the fact that the sum of the total carbon plus silicon contents in the whole of these specimens is approximately 7, a figure considerably in excess of that contemplated by Piwowarsky in Fig. 6. In addition to providing an interesting commentary on the danger of adopting this empirical summation of total carbon plus silicon as a basis of expressing relationships in connection with the properties of cast irons, it serves to show that his conclusions are valid for a narrow range of conditions only.

25. The part played by the graphite not only in the magnitude of the improvement in mechanical strength properties but also in the actual mechanism of hardness as revealed by these results, is of special importance and introduces considerations and

Table 5

COMPOSITION OF CAST IRONS—SCHWARTZ AND VATH EXPERIMENTS

Type of Iron	T C Per Cent	Si Per Cent	Mn Per Cent	S Per Cent	Ph Per Cent	Ni Per Cent	Cr Per Cent
Alloyed Cylinder Iron.....	3.15	1.90	0.62	0.018	0.46	1.04	0.35
Non-Alloy Cylinder Iron..	3.02	2.03	0.62	0.032	0.55	....	....
Foundry Iron.....	2.99	1.92	0.62	0.030	0.73	....	....
Phosphorus Foundry Iron..	3.20	2.45	0.70	0.105	1.37	....	....

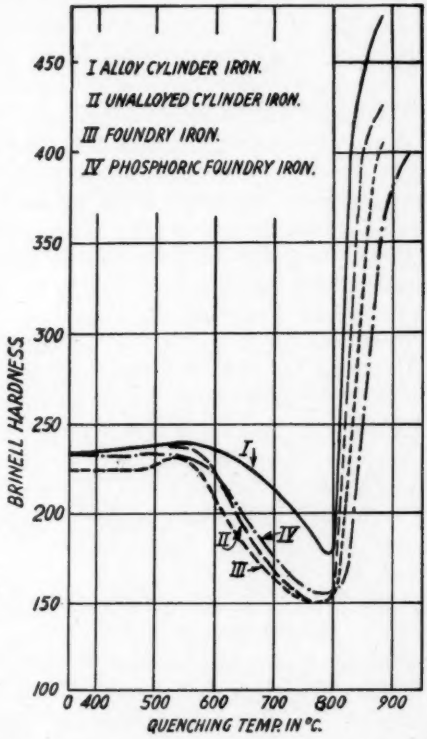

FIG. 11—HARDNESS AFTER QUENCHING FROM VARIOUS TEMPERATURES (SCHWARTZ AND VATH).

phenomena different from those experienced in the hardening and tempering of steels. In an investigation of the hardness of four irons whose compositions are shown in Table 5, after quenching

from different temperatures Schwartz and Vath[6] obtained the results as shown in Fig. 11.

Quenching Temperatures

26. Quenching from temperatures within the range of approximately 550 to 790° C. (1022 to 1454° F.) in each case is accompanied by a drop in hardness from that of the original "as-cast" condition. From temperatures in excess of from 775 to 790° C. (1427 to 1454° F.), quenching is accompanied by the hardening effect and apparently in these specimens and under the conditions of the experiment, the maximum hardening effect is obtained with quenching temperatures in the neighborhood of 900° C. (1814° F.). It is known that when cast irons are heated within the temperature range of 550 to 790° C. (1022 to 1454° F.), the combined carbon undergoes decomposition. It is suggested that the softening effect on quenching from these temperatures, as revealed by these results, is due to this cause, a fact which suggests that under many conditions the decomposition of the combined carbon, pearlite, initially present in the cast iron, may be a preliminary to hardening by quenching from temperatures high enough to secure the solution of the graphite thus formed.

27. Considerations of this nature have an important bearing upon the question of the most effective quenching temperature. It is quite conceivable that, according to the extent to which hardening is dependent upon the resolution of the graphite, the quenching temperature necessary to obtain the most effective hardening, from the point of view of hardness alone, may be much further above the AC_3 point than is the case in steels. Something after this nature is apparent from the results of Schwartz and Vath, previously quoted.

28. In spite of this, in some careful experiments conducted by the author[7] in an investigation of the effect of quenching temperatures, effective hardening was obtained by quenching in oil from 800° C. (1472° F.), the hardness value attained being constant over a range of quenching temperatures from 800 to 860° C. (1472 to 1580° F.) and actually falling slightly at a quenching temperature of 920° C. (1688° F.). The strength results obtained in these experiments after quenching and tempering at various temperatures are illustrated in Fig. 12. In the quenched condition, while the hardness was constant over a quenching range of 800 to 860° C. (1472 to 1580° F.), the strength fell off substan-

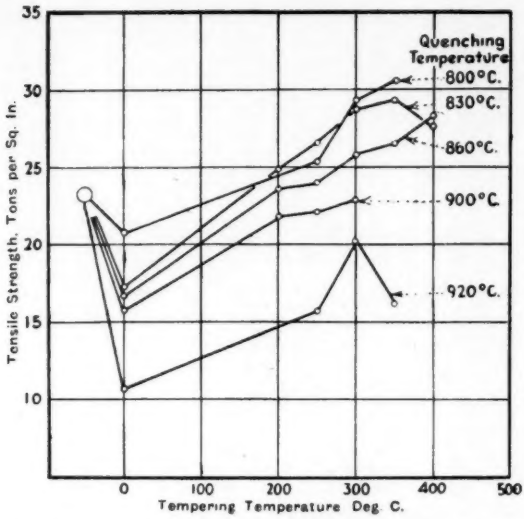

FIG. 12—SHOWING THE INFLUENCE OF QUENCHING TEMPERATURE ON TENSILE STRENGTH AFTER TEMPERING.

tially with increased quenching temperature. The highest values of strength under all conditions of quenching and tempering were obtained with the lowest quenching temperatures.

29. It is important to add that these experiments were carefully carried out on thin specimens of centrifugally-cast material and that in actual practical experience with this same class of material, it is preferable to adopt a quenching temperature within the range of 850 to 875° C. (1562 to 1607° F.).

THE INFLUENCE OF CHEMICAL COMPOSITION AND ALLOY ADDITIONS

30. From experiments conducted on centrifugally-cast material, it has been shown that in suitable thin sections, plain unalloyed cast irons are susceptible to the hardening and tempering treatment. Of the elements present normally in cast iron, phosphorus has been systematically studied. The results referred to in the first section of this paper have been largely taken from this study and, while the investigations were made with a cast iron containing chromium, it is probable that they can be regarded as indicating the characteristic influence of phosphorus.

Effect of Phosphorus

31. The range of phosphorus content studied was from 0.035 up to 1.56 per cent and while the hardening effect after quenching and tempering was obtained with all phosphorus contents, the most uniform results were obtained with the lower phosphorus content materials. This will be clear from Figs. 2, 3 and 4 and the stress-deflection curves in Figs. 7 and 8. In these specimens and under these particular experimental conditions, the best results, as measured by increase in hardness and improvement in strength properties, are obtained with phosphorus contents below 0.6 per cent.

32. A point that cannot be overstressed is that, by heat treatment in this manner, substantial improvement in the resilience value or toughness can be obtained. Reference to the results in Table 6, which are the numerical values assigned to the included

Table 6

INCLUDED AREAS OF STRESS/DEFLECTION CURVES. VARYING PHOSPHORUS SPECIMENS

Specimen No.	1.	2.	3.	4.	5.	6.	7.
Phosphorus. %	1.56	1.30	1.06	0.63	0.58	0.43	0.035
	sq. in.	sq. in.	sq. in.	sq. in.	sq. in.	sq. in.	sq. in.
As cast.....	4.0	4.0	4.8	4.8	5.9	6.4	7.1
H. and T. at 250° C.	3.6	4.8	4.8	8.6	6.5	8.4	11.2
" " 300° C.	6.6	5.6	6.5	6.1	7.4	5.2	14.4
" " 350° C.	4.5	4.6	6.1	6.4	7.5	10.9	14.5
" " 450° C.	5.1	4.0	5.6	5.3	5.9	7.1	19.6
" " 600° C.	4.2	4.2	...	5.2	5.8	7.2	11.1

areas of the stress-deflection curves, will be sufficient to show how substantial this can be, particularly in the lower phosphorus members of the series. Results of this nature are as remarkable as they are unexpected with cast iron and serve to show that every confidence can be placed in the strength properties of cast iron in the hardened and tempered condition.

Effect of Alloys

33. As would be expected, the influence of alloy additions is accompanied by marked improvements in the results obtained and, as in the case of steels, the outstanding alloying elements are nickel, manganese, chromium and molybdenum. The influence of these elements, exerted through their influence on the position of the

critical points A_3 and the critical speed of quenching, is utilized to provide effects similar to those which accompany their use in steels. In the case of nickel, its important influence on the depth of penetration of the hardening effect is shown clearly by the following experimental results obtained on chill cast bar specimens of the analyses as recorded in Table 7.

Table 7

CHEMICAL ANALYSES OF SPECIMENS OF VARYING NICKEL CONTENTS

Spec. No.	T C Per Cent	C C Per Cent	Gr Per Cent	Si Per Cent	Mn Per Cent	P Per Cent	Ni Per Cent	Cr Per Cent
1	3.71	0.57	3.14	1.92	0.96	0.45	Nil.	0.11
2	3.76	0.41	3.35	1.97	1.02	0.48	1.18	0.11
3	3.71	0.43	3.28	1.92	0.96	0.47	2.05	0.11
4	3.71	0.36	3.35	1.92	0.99	0.49	2.97	0.15
5	3.71	0.43	3.28	1.97	0.94	0.47	4.10	0.15

Table 8

BRINELL HARDNESS VALUES OF SPECIMENS IN TABLE 7 IN ANNEALED CONDITION

Diam. of Bar	Nickel Contents, Per Cent				
	Nil.	1.18	2.05	2.97	4.10
1.75 ins.	212	217	228	207	228
4.0 "	207	196	207	212	228
5.5 "	179	187	196	187	217

34. Prior to hardening, all the bars were submitted to a uniform annealing treatment at a temperature of 900° C. (1652° F.). After this treatment, the Brinell hardness results on the outside surfaces of the bars were as shown in Table 8.

35. Cross sections of the varying diameter bars cast, as indicated in Table 8, were hardened by quenching in oil from a temperature of 875° C. (1607° F.) and the Brinell hardness values across the section, from the edge to the center, determined. These results are given in Figs. 13, 14 and 15 and show clearly the influence of nickel in improving the depth of penetration of the hardening effect. In this case, 2.0 per cent nickel ensures a hardness value of at least 375 in the center of the 4-in. diameter bar.

36. An important aspect of alloy additions to cast iron for hardening and tempering is their effect on the magnitude of the improvement possible in strength properties after suitable treatment. This improvement in strength persists not only at the point

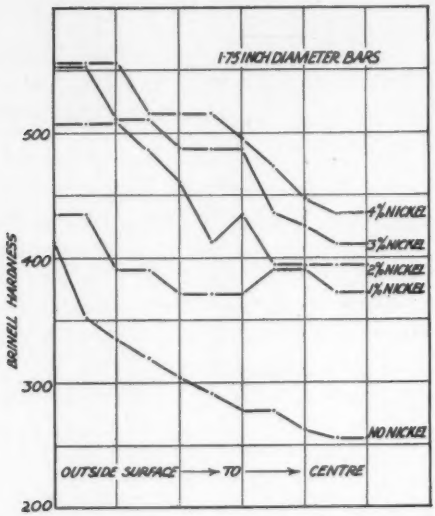

FIG. 13—EFFECT OF VARYING NICKEL CONTENTS ON DEPTH OF HARDENING ON 1.75-IN. DIAMETER BARS.

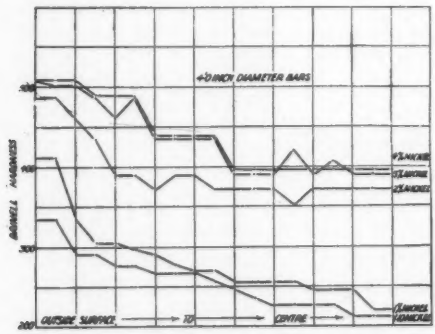

FIG. 14—EFFECT OF VARYING NICKEL CONTENTS ON DEPTH OF HARDENING IN 4-IN. DIAMETER BARS.

of maximum strength in the hardened and tempered condition, but even after tempering to a hardness value equal to the original "as-cast" condition. Improvements in strength values of about 50 per cent have been recorded.

Effect of Molybdenum on Nitrogen-Hardening Cast Iron

37. This is not the place to detail the results which have been

obtained from various alloy cast iron compositions, as many results on plain, nickel-manganese, nickel-chromium, molybdenum and alloy compositions containing vanadium, aluminium, titanium and other alloy additions have been published already. However, it is impossible to pass from these considerations without making reference to the important results obtained from the joint additions of molybdenum-manganese. With combinations of manganese and

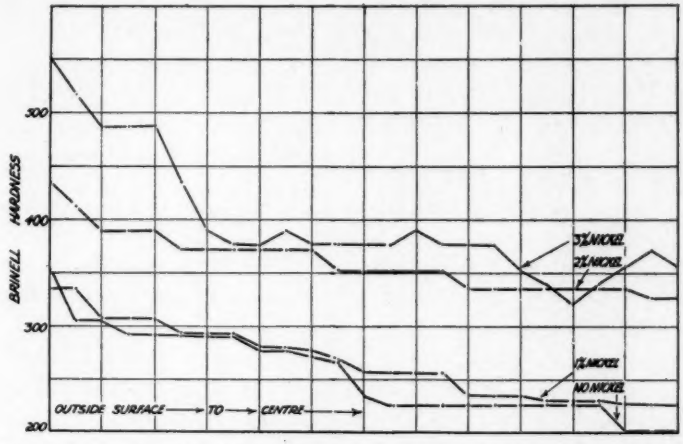

FIG. 15—EFFECT OF VARYING NICKEL CONTENTS ON DEPTH OF HARDENING IN 5.5-IN. DIAMETER BARS.

molybdenum, strength values of a very high order are obtained after suitable hardening and tempering treatments.

38. Reference might be made here to some experimental work on the influence of molybdenum additions on the properties of an aluminium-chromium-nickel cast iron, after exposure to treatment at a temperature of 500° C. (932° F.). Some of these results, which have been published already,[8] were carried out on an aluminium-chromium alloy cast iron suitable for nitrogen hardening and it was observed that, when nickel was present particularly, there seemed to occur a marked falling off in strength properties after exposure to the nitrogen hardening treatment at a temperature of 500° C. (932° F.) for a period of 90 hours. These results appeared to bear some resemblance to the phenomena of temper brittleness in steels which at once suggested the possibility of exploring the influence of molybdenum. The results published already show clearly that molybdenum, either alone or in conjunc-

tion with aluminium, does not bring about any reduction in strength after low temperature treatment under nitrogen hardening conditions, and that it is effective also in preventing the reduction in strength under these conditions when nickel is present in the alloy.

39. While these results were determined under nitrogen hardening conditions, a subject outside the scope of this paper, their apparent disclosure of the possibility of the existence of a phenomenon in alloy cast iron similar to temper brittleness in steels, is of importance in connection with the heat treatment of cast iron by hardening and tempering and is a discovery worthy of the attention of other investigators in this field.

Effect of Alloys on Quenching Speed

40. The effect of certain alloy additions in increasing the critical quenching speed can be taken advantage of in the production of alloy cast irons suitable for air hardening treatments. A typical example[7] is the nickel-chromium alloy of the following specification:

		Preferred Composition
Total Carbon, Per Cent	2.70 to 3.50	3.00
Silicon, Per Cent	1.00 to 3.00	1.80
Manganese, Per Cent	0.5 to 1.5	1.00
Sulphur, Per Cent	0.14 max.	0.06
Nickel, Per Cent	3.00 to 6.00	4.50
Chromium, Per Cent	1.50 to 2.00	1.75

41. This alloy cast iron can be hardened by heating to 800 to 850° C. (1472 to 1562° F.) and allowing it to cool in air and can be softened by a tempering treatment at 680° C. (1256° F.). The effect of air hardening and tempering treatments on the mechanical strength properties follow the same lines as the quench-hardening and tempering treatments described already. The author has described previously[7] the air hardening properties of an alloy cast iron containing nickel, manganese and chromium of the following complete analysis:

Total Carbon, Per Cent	3.49
Graphite, Per Cent	2.76
Comb. Carbon, Per Cent	0.73
Silicon, Per Cent	2.80
Manganese, Per Cent	2.26
Nickel, Per Cent	1.04
Chromium, Per Cent	0.57

Hardening and Tempering and Internal Stress

42. Experimental work on the influence of hardening and tempering on internal stress conditions has been carried out by the aid of ring specimens.[2] When cutting gaps in test rings of this form, it is noticed that the cut ring may show a tendency to open or close. By cutting the gap in the ring while it is held in a clamp, the gap as cut can be measured. The difference between this gap measurement and the free gap measurement after the release of the clamp indicates the amount of gap movement. The amount of gap movement recorded in inches, a positive gap movement indicating opening and a negative gap movement indicating closing, enables a comparative study of the changes in internal stress conditions to be made.

43. In a comparative study of these conditions in the samples whose compositions are recorded in Table 1, all the specimens in the "as-cast" condition showed positive gap movements and, while the variation in magnitude of the gap movements was irregular, the initial presence of internal stresses is indicated. In the hardened condition, all the specimens, without exception, showed negative gap movements and, while this negative movement or closing of the gap varied in magnitude, the movement was of a substantial order and indicates a complete reversal of the condition of internal stress from that present in the material in the "as-cast" condition.

44. In the tempered specimens, while the individual variations recorded were still irregular, in all cases up to a tempering temperature of 450° C. (842° F.) the gap movements were negative in sign. With a tempering temperature of 600° C. (1112° F.), all the gap movements reverted to the positive sign, that is, in gap opening, but lower in magnitude than those of the material in the original "as-cast" condition. Numerous additional experiments appear to confirm that the hardening operation is accompanied by a complete reversal of the internal stress condition as made manifest by the gap movement in slitted rings and tempering at successively higher temperatures is accompanied by a progressive recovery until the characteristics of the "as-cast" condition is obtained. Some of the actual results obtained on the specimens referred to are illustrated in Fig. 16.

45. It will be appreciated at once that they indicate the existence of something in the nature of a critical tempering tem-

perature at which the internal stress condition, as revealed by the gap movement, is zero. By replotting the gap movements in relation to tempering temperatures, as in Fig. 16, it would appear that this critical tempering temperature for these specimens lies within the range of 500 to 570° C. (932 to 1058° F.). This observation is one of obvious importance in the practical heat treatment of cast iron by hardening and tempering.

46. However, its importance does not quite end there. Further experiments on specimens of the same material subjected to a stabilizing treatment at 550° C. (1022° F.) for 20 minutes and an annealing treatment at 900° C. (1652° F.) for 50 minutes, followed by slow cooling, failed to remove the internal stress (gap

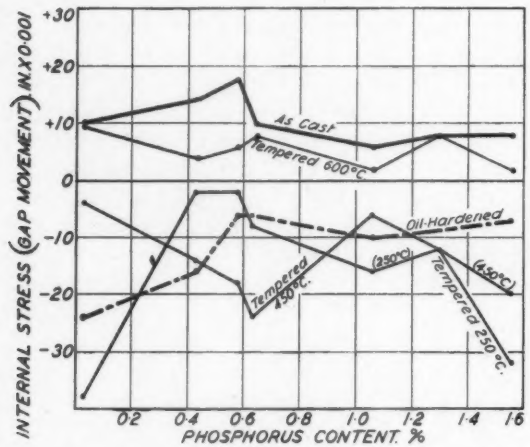

FIG. 16.—GAP MOVEMENT (INTERNAL STRESS), AS CAST, HARDENED AND TEMPERED.

movement) as present in the original "as-cast" material. In fact, these treatments appeared to result in an increase in the gap movement and consequently in the internal stress. From these results, it is almost impossible to resist the conclusion that these stabilizing and annealing treatments actually increased the internal stress condition and certainly the only way of obtaining a gap movement of nil was by quench hardening and tempering at the critical tempering temperature. It is also of interest to record that the hardening and tempering of these specimens after submission to the stabilizing and annealing treatments brought about varia-

tions in internal stress characteristics of a similar nature to those recorded for the treatment of the "as-cast" specimens.

47. In presenting this study of the heat treatment of cast iron by hardening and tempering, the author has endeavored to review the results of investigations which have accrued during the past few years. Those who are interested in the development of cast iron as a constructional material, will derive no small sense of satisfaction from the knowledge that it responds to heat treatment methods and that by such means, modifications in properties of utilitarian value can be obtained. In the case of other metals and alloys, heat treatment of this nature has proved to be a facility which has played a very big part in their extended development and it may play a similar part in the case of cast iron.

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DISCUSSION

CHAIRMAN DR. J. T. MACKENZIE[1]: This paper on the "Heat Treatment of Cast Iron by Hardening and Tempering" is by J. E. Hurst, President of the Institute of British Foundrymen, Technical Director of Sheepbridge Stokes Centrifugal Castings Co., Ltd., Chesterfield and of Bradley and Foster, Ltd., Darleston, England. The Sheepbridge Stokes company makes a large proportion of the cylinder liners and piston rings used in the trucks, buses and many of the cars in England. Bradley and Foster, Ltd., are makers of refined pig iron which is used considerably in England for the production of heavy-duty cast irons.

Mr. Hurst, I believe, has done more for the commercial application of hardening and tempering of cast iron than anyone I know. He is doing it on a large scale and has been for some time.

This paper is the official exchange paper of the Institute of British Foundrymen and, in absence of the author, will be presented by G. P. Phillips, International Harvester Co., Chicago, Ill.

MR. PHILLIPS: I would like to point out that Mr. Hurst has stated that his own investigations are primarily responsible for the knowledge that the strength properties of quenched material may be improved by proper tempering.

In October, 1924, J. W. Bolton published a brief article on "Heat Treatment of Cast Iron" in *Iron Age*, in which he pointed out and showed data on this same phenomenon that by tempering after quenching he obtained decided improvements in the physical properties. I believe that it is fitting that we should point that out at this time.

CHAIRMAN MACKENZIE: Most of these specimens are small piston rings, 3½ or 4 in. diameter; the ring is split and pulled apart to determine the tensile strength and modulus of elasticity.

The so-called En value in the British specifications is obtained by loading the ring until the gap shows so much increase. The relation of increase to load is En value.

J. W. BOLTON[2]: Dr. MacKenzie, in his opening remarks made a inference that is hardly correct. It is true in this country the degree of advertising and of exploitation of the commercial heat treatment of cast irons may not have reached the point it has abroad. However, three investigations, those of Frank Coyle, presented before the A.S.M.; Potter, presented before the A.F.A., and of the speaker, published in the *Iron Age*, led to developments far beyond the laboratory stage. There have been a number of different types of iron castings made and heat treated by quenching and drawing prior to 1930. These were in a number of different designs and used for various applications. Many tons of iron were so treated commercially.

CHAIRMAN MACKENZIE: I am glad to be corrected on that. I would like to point out in this discussion of the phosphorus that Mr. Hurst allowed the common error in such tests to creep into his. He has 3.81 per cent carbon with the 0.04 per cent phosphorus, but drops to 3.39 per

[1] Metallurgist and chief chemist, American Cast Iron Pipe Co., Birmingham, Ala.

[2] Metallurgist, Lunkenheimer Co., Cincinnati, O.

cent carbon with his 0.156 per cent phosphorus. That is quite a common error. In adding phosphorus, you can hardly help the carbon dropping off.

D. A. YATES[3]: Mr. Hurst shows the permanent set values in percentage but he gives nothing with respect to the amount of load which permits him to arrive at those permanent set values. I think that is very important.

I think it is also interesting to point out the fact that even though the higher phosphorus content shows lower tensile values, as shown in his report, they show much less permanent set values, which we have found to be much in line.

W. H. SPENCER[4]: This paper gives an extremely interesting and quite detailed account of the development in the piston ring and sleeve business. While there has been some work done along these lines in the United States, there has not been much published on the tempered or hard piston rings. There is one point which I would like to see clarified and that is the reference to the distortion which is produced by the heat treatment and the control of this distortion.

MR. YATES: Hardened piston rings have been used for quite some time in the automotive game and the tractor industry. But for some reason, that practice has been discontinued. One notable case is that of a large Diesel tractor company. In their Diesel engines, some years ago, they used alloyed, hardened, tempered cast iron. However, they have reverted to the alloyed-high phosphorus as-cast type piston ring.

CHAIRMAN MACKENZIE: I might state the principal combination that Mr. Hurst puts out is the nitrited cylinder liner with his hardened, tempered piston rings. He has some very remarkable wear tests on cars run in different parts of the world.

On page 24, I believe it is, and one other place in the paper he says it is "almost impossible to resist the conclusion," and I would take it that he was trying to resist the conclusion and I do not see why.

J. E. HURST (*Submitted as Written Closure*): I should like to take this opportunity of placing on record my personal thanks to the Chairman, Dr. J. T. MacKenzie, and to Mr. Garnett Phillips, who kindly undertook the task of abstracting my paper.

I thank both Mr. Phillips and Mr. Bolton for their reference to the work on the "Heat Treatment of Cast Iron by Hardening and Tempering" which has been done in America. Reference to this was made in the bibliography at the end of the paper. I think it is perfectly clear that heat treatment of cast iron for the purpose of hardening has been practiced for a very long time, and it is quite clear that the effect of tempering in improving the strength properties after the hardening, has been partially understood for a considerable time also. It is equally true that the full effect of hardening and tempering on the physical and mechanical properties of various types of cast iron, has only been appreciated for the past few years, and is due to the intensive investigation work carried out during this period.

With reference to Dr. MacKenzie's remarks on the phosphorus and total carbon contents of the series of specimens referred to in my paper,

[3] Metallurgist, McQuay-Norris Piston Ring Co., St. Louis, Mo.
[4] Metallurgist, Sealed Power Corp., Muskegon, Mich.

I am quite aware of the drop in total carbon content with increasing phosphorus content throughout this range of specimens, and in the original paper I endeavored to take this into consideration.

Mr. Yates asked for information regarding the stress value at which permanent set values were obtained. The stress value used in this determination was 14 tons (31,360 lb.) per sq. in. calculated in accordance with the relationship laid down in B.S.I. Specification 5004. This is a purely arbitrary value and is used by us in our testing procedure, as it happens to be approximately the stress set up in a piston ring of British standard dimensions in springing it over the piston. I am very glad to note that his experience of the effect of phosphorus on the permanent set values is very much in line with my own.

With reference to the remarks of Mr. Spencer and Mr. Yates, I should like to make it clear that my paper was not concerned in any way with hardened piston rings, and that I expressed no opinion regarding the value or performance of such piston rings. It just so happens that the method of testing used by myself in investigating the effect of hardening and tempering on the properties of cast iron, is the same method as that used in testing piston rings.

My friend, Dr. MacKenzie, referred in a very nice manner to the nitrogen hardened cylinder liners which we manufacture in this country, and here again this is outside the scope of my paper, and I feel that it would be out of place to amplify my reply to the discussion by any comments on these remarks.

Finally, I would like to say how glad I have been to have had the opportunity of presenting this Exchange Paper, but was sorry I was not able to be present in person at the convention and hope that it will be appreciated that only the many additional duties that I had imposed upon me as President of our own British Institute prevented me from coming over.

Foundry Sand Testing Problems at High Temperatures

By P. E. Kyle*, Boston, Mass.

Abstract

This paper reviews the published data on the properties of foundry sands at elevated temperatures. The data are plotted and the results discussed. The drastic temperature effects are shown to be confined to a comparatively thin layer of sand adjacent to the casting. Test methods for determining conditions at elevated temperatures are described, these being tests for refractoriness, expansion and contraction, permeability, and compressive strength. Data on these tests are given and discussed. Suggested lines of research are presented as being needed to supply data which are needed.

1. In spite of the most recent developments in such fields as permanent mold casting and pressure die casting, there still remains the wide use of sand as a molding material. In fact, sands are relied upon where metal molds have proved themselves unsatisfactory. This particular use is, by its nature, one where high temperatures are encountered and this is one of the most important factors limiting the application of these processes.

2. Much information has been available for some time regarding the properties of molding sands at normal room temperatures. When we consider the wide use of routine sand analysis and test methods as a means of shop control of cast products, there can be no question as to its usefulness.

3. There is no doubt, however, in the minds of foundrymen that there are still problems which have not been solved by testing sands at normal temperatures. The first step in an investigation to determine the causes of our present troubles seems to be the determination of the properties of molding materials at the temperatures to which they are subjected in the casting process.

* Instructor in Mechanical Engineering, in charge of Foundry Laboratory, Massachusetts Institute of Technology.

Note: This paper was presented at a session on Sand Research at the 1936 Convention of A. F. A. in Detroit, Mich.

4. The search for profitable projects along these lines is the event which occasioned the preparation of this paper. In our sand control laboratory at the Massachusetts Institute of Technology we have a complete setup of equipment for the standard tests of the A.F.A. and have facilities for conducting research work in the fields we are at present discussing as well as others.

5. After looking over much of the literature it was decided that while only a few articles have been written,[1*] considerable knowledge of the problem could be obtained by studying these and plotting data of all of the results on a single sheet. This has been done and the summarizing of these test methods and results is all that is claimed in this paper since very little work has been actually completed by the author.

6. Realizing the value of this review to us in opening up new fields for student research problems, it is hoped that others may likewise profit and perhaps avoid much duplication of effort.

TEMPERATURE IN SAND MOLDS ON POURING CASTINGS

7. Before devising test methods it is very important to know the range of temperatures to be expected in practice, the time necessary to reach these temperatures, and how much of the sand is involved in this temperature change. One of the most simple testing setups which has been used to obtain these results consists essentially of a set of thermocouples placed at various distances from the mold. Data are taken over a period of time following the filling of the mold. In one investigation there was one couple inserted in the mold cavity and the solidification curve for the iron was determined. In some cases difficulty was experienced in locating these couples exactly so they were placed approximately in position and after pouring, the mold was taken apart carefully and the exact locations established[2, 3].

8. Curves in Fig. 1 show typical results taken from two reports where this method of temperature measurement was employed. Of interest is the fact that mold surface temperatures rise suddenly and the rate of heat transfer back into the mold is not always appreciable. For example in the pouring of iron it takes over 15 minutes before the free water is driven out of the sand at a distance only slightly over one inch from the casting. This same temperature rise takes place in less than 4 minutes in the case of a steel casting poured at a higher temperature.

* Superior numbers refer to bibliography at the end of the paper.

9. Data of this nature have been obtained satisfactorily in a few instances with iron and steel castings. Sufficient information is not available to permit the determination of any laws of heat transfer in mold materials. By noting such effects as shown in Fig. 1 it is possible to suggest likely methods of testing many properties of sands and these points will be discussed more fully in the following sections.

REFRACTORY PROPERTIES OF MOLDING SANDS

10. There have been many tests made on the refractoriness of foundry sands and in general there have been several methods used in securing test data.

Cone Test

11. The usual test for the refractoriness of any material is to form small cones and study the action of the bending of the tip under high temperature conditions. This method has been used satisfactorily[9] to determine the effect of the character and content of clay materials on the breakdown of the cone. In Trainer's work[9] it was noted that sand-clay mixtures failed by complete bending at the temperature of fusion of the clay when there is 50 per

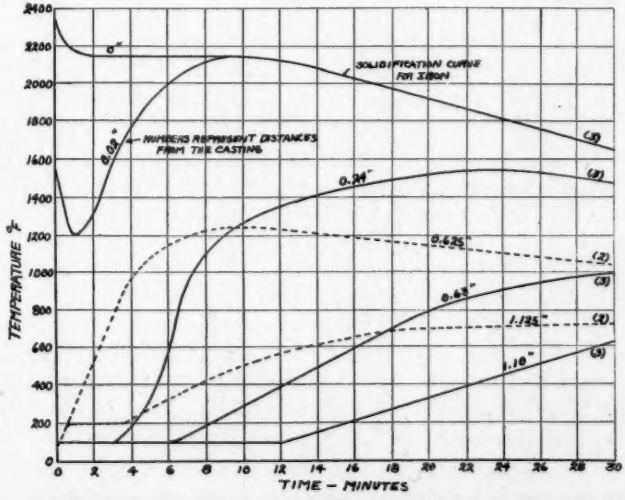

FIG. 1—MOLD TEMPERATURE DATA. THE SOLID LINES REPRESENT DATA OF MOLDS POURED WITH IRON INTO BLOCKS 10½ INS. DIAMETER AND 1¼ INS. THICK. THE DOTTED LINES, REPRESENT DATA FROM MOLDS POURED WITH STEEL INTO BLOCKS 8 IN. x 8 IN. x 1 IN.

cent clay present. For materials with less clay the failure takes place at a higher temperature. While tests were not carried to the fusion point of the quartz sand grains, most results indicate that the failing temperature approached this point as the clay content reached zero. In any event cone tests do not give much data of a quantitative nature.

12. A modification of this same type of test has been suggested in the form of a supported beam of a sand-clay mixture under high temperature conditions. In this test the amount of sag is taken as a quantitative measure of the fusion properties.

Full Fusion Test

13. Full fusion tests on cones of molding sands give the true melting points. To the foundryman, however, there is another point well below this true melting point which is of importance and which would still be called refractoriness. This lower limit of the fusion range is the temperature at which the sand sinters and burns on the casting. The item of cleaning cost makes this sintering action an economic problem.

Sintering Test

14. The Saeger sintering test* is well known to the foundry industry and will not be described in too much detail here. Essentially it consists in placing a heated platinum ribbon in contact with a sample of molding sand and noting the ribbon temperature at which sintering or "burning-on" of the sand takes place. This test can be used to advantage also in determining the sintering points of such materials as clays, sands, core mixtures, sea-coal mixtures, core washes, and mold blackings.

Pouring Test

15. The other general method of attack has been the actual pouring of castings and careful noting of the conditions of "burning-on". This seems to be very practical but has not been used to any great extent. The only case where this test was used[4] showed that there was an inverse relation between the sintering point and the burning on effect.

* *Sintering Test of Molding Sand—Tentative Standard,* Testing and Grading Foundry Sands, American Foundrymen's Association, (1931), pp. 108-112.

Penetration of Metal in Sand

16. Closely connected with the refractory property of sands is the ability to stand the pressure of the metal and prevent it from flowing between the grains. Grains of sands having a low sintering point might easily fuse together and close the passages between them and prevent the flow of metal into these regions. In the case of the high sintering point sands this melting would not take place and the common effect of "burning-on" would be noted. These experimental data might well serve as an explanation of the inverse relation mentioned above.

EXPANSION AND CONTRACTION

17. The problem of expansion and contraction of molding sands is very important from the standpoint of surface defects and

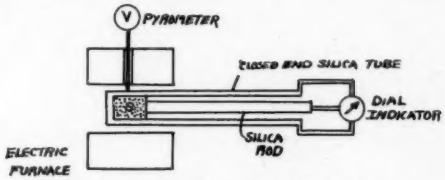

FIG. 2—EXPANSION TESTING APPARATUS.

casting size. If castings are to be made smooth and closer to dimension in sand molds, the problem of expansion, which perhaps can never be completely eliminated, must be minimized.

Testing Apparatus

18. Fortunately there seems to be no question regarding the type of apparatus used in determining this property of refractory materials. The usual type of dilatometer as shown in Fig. 2 has been used extensively[1]. Essentially it consists of a furnace in which the specimen is placed and a dial indicator so located as to read the changes in length of the specimen. The apparatus illustrated restrains the sand in a tube and permits expansion only along the length of the piece. In the most recent investigation[6] the sample was not so constrained while the remaining features of the apparatus were essentially the same. There might be some doubt as to whether such results with the two types of machines are comparable but a short investigation with the same sand would explain the differences which would presumably be small.

Important Factors in Testing

19. The other factors of importance in this testing procedure are the rate of heat application and the time the specimen is kept at temperature. In molding sands there are silica sand grains and clays, each composed of many materials. In a material so complicated in its makeup there may be such phenomena as critical heating rates. The length of time a sample is held at temperature before measurements are taken must also be included as a factor, particularly where any of the constituents are burned out.

Behavior of Quartz or Silica Grains

20. In general when studying the properties of complex materials it is impossible to explain their behavior by noting the behavior of each of their constituents. The geologists have been able to help considerably in their studies of the expansion of silica in the form of quartz and of the transformations at higher temperatures[4, 5]. At temperatures about 1100° F. there is a change in the form of quartz from the alpha to the beta form. At this point there is a small, but critical expansion which takes place rapidly and causes a splintering of the grains. This would cause a considerable roughening of the mold surface.

21. The greatest expansion of quartz takes place on first heating, at temperatures around 2300° F. and is the result of the transformation into cristobalite. This change takes place slowly at this temperature but at 2800° F. it may be completed in about 1 hour and the expansion under these conditions might be as high as 15 to 20 per cent.

22. Since molding sands are composed principally of these silica grains the expansive properties expected might be somewhat comparable. As a matter of fact there are similar changes but usually not of such sudden occurrence and over a range of temperatures rather than at a specific temperature. In attempting to understand these differences the logical procedure would seem to be to study the clay materials which make up the remainder of the molding mixture.

Behavior of Bonding Clays

23. Bonding clays contain essentially mineral constituents in a very fine state and depend for their bonding power on previous mixing with water. During the casting process, changes take

place in the clay as well as in the silica sand grains. First the free water added is driven off at some temperature close to 212 to 215° F. Between 850 and 950° F. about 50 per cent of the combined water in the form of hydrates is lost and by further heating at 1100° F. all of this water is removed leaving the clay in such a condition that it cannot be restored as a binder.

24. Under casting conditions, then, the grains of silica expand and at about the same time the clay undergoes changes. This action would be most severe at the mold surface where cracking would cause surface defects on the casting. Since this is a mold surface change, from the point of view of sand reclamation the problem of complete ruination of sand involves a fairly small percentage of the mold.

25. As originally stated, this expansion phenomenon can at best be minimized. In the same way that complexity of makeup may increase expansion so may further complexity by additions of other materials cause decreases. Recent data[6] have shown that decreases can be realized in a number of ways. Further study cannot help but point out other means of producing a greater decrease in expansive properties.

FLOWABILITY

26. The flowability of molding materials is a property of which we know very little. At normal temperatures it would be a measure of the ease and completeness of mold ramming, particularly in machine molding, and at the high temperatures it could serve to indicate the possibility of casting distortion due to the mass of metal crushing out the sand in the drag. So far there has been no accepted method of test so any research much start with the development of testing equipment.

COMPRESSION STRENGTH

27. A test which includes many factors influential in other properties of molding sands is the test for compressive strength. Some data have been collected on the change in strength at elevated temperatures[1, 13]. Fig. 3 illustrates typical apparatus for conducting tests of this character. There are several difficult problems in designing a setup of this type but they are not fundamental in the determination of strength properties.

28. The apparatus shown in Fig. 4 is used for qualitative

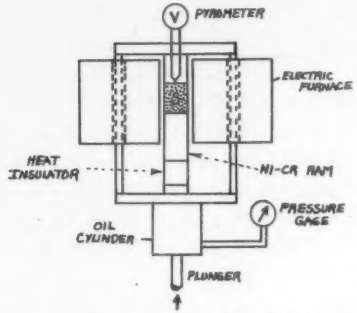

FIG. 3—HIGH TEMPERATURE COMPRESSION TESTING APPARATUS (HUDSON).

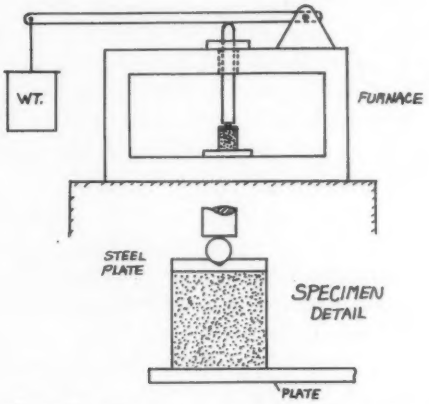

FIG. 4—HIGH TEMPERATURE COMPRESSION TESTING APPARATUS (MASSACHUSETTS INSTITUTE OF TECHNOLOGY).

results in the foundry laboratory exercises in sand testing at the Massachusetts Institute of Technology. After running through all of the standard tests one or two samples are run at elevated temperatures. This helps to bring out the fact that the results of tests made under casting temperature conditions may vary widely from test data obtained at room temperature.

29. The first things to determine in this problem of dry compression strength are, how long and at what temperature a mold material must maintain its strength and what this strength must be under given conditions of casting practice. Tendencies have been to test at high temperatures without consideration of the

proper procedure and to not reporting in sufficient detail the procedure actually used. As a result much possibly valuable data of much possible value have been made worthless to the industry.

30. At normal temperatures it is fairly certain that the temperature gradient from the surface to the center of a test specimen is small. At high temperatures we can maintain conditions before test sufficiently long to get a similar small gradient. However, the question of whether or not the time needed to do this is sufficient to cause other variations in the amounts of clay burned out or the amounts of expansion from surface to center has not been settled. These factors when considered in the discussion of expansion properties were found to be very critical and they should be much more critical in strength tests where the quantity to be measured is the bonding power of the clay which varies so much with time of heating.

31. During some tests it has been noted that on sudden heating (probably at a rate comparable to the rate of heating of mold surfaces) the specimens were cracked and the results so obtained were quite radical. Such radical results are not surprising when one considers how irregularly casting defects show up under presumably similar conditions of foundry practice. After careful investigation it may very likely turn out that it would be better to test under high rates of heat application and then try to eliminate surface cracks and inconsistent test results, rather than to heat from 4 to 5 hours before testing.

32. In general it is not possible to divorce expansion and compressive strength properties in the development of molding mixtures. In some cases it has been noted that stands having the greatest expansion also have the highest strength at high temperatures. If these results do pertain to our present molding materials there is an open field for the investigation of these related properties and their effects on casting defects. In this connection it should be noted that high strength is not always desirable.

33. Another line of investigation pertaining to bond properties as measured by compression tests is the change of strength after cooling from elevated temperatures. This is of importance in determining the ease and expense of shaking out.

PERMEABILITY

34. In the determination of sand permeability at high temperatures a typical setup is shown[8] in Fig. 5. Essentially it con-

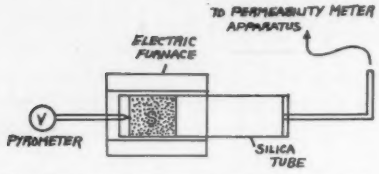

FIG. 5—PERMEABILITY TESTING APPARATUS.

sists of a silica tube containing the rammed specimen which is placed in a furnace. The air line from a permeability meter is connected through a closed end of the tube outside the furnace.

35. In testing by passing a certain volume of gas through the specimen the condition of gas expansion must be accounted for. In a mold there is a variable amount of gas material being formed depending on the temperature and composition of the metal and the mold material. In attempting to explain test results as shown in Fig. 6 it is possible to realize how important the testing procedure may become. The heavy curves show permeability readings taken with varying amounts of sea-coal by the orifice method. The dotted curves are for readings taken by passing the standard

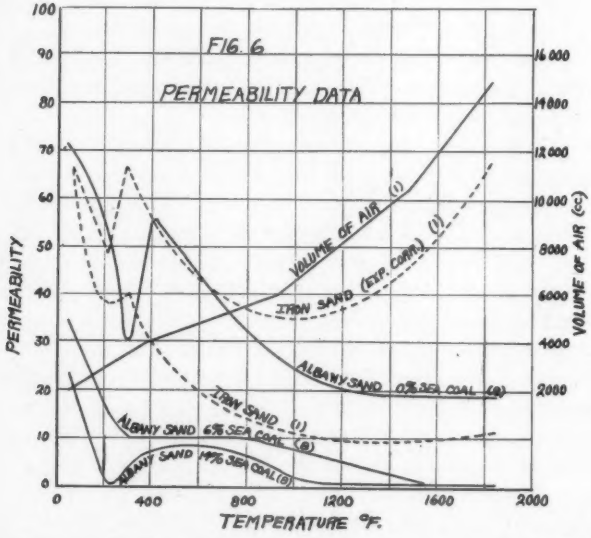

FIG. 6—PERMEABILITY DATA OF SANDS UNDER HIGH TEMPERATURES. DOTTED LINES INDICATE TESTS BY STANDARD TEST PROCEDURE. SOLID LINES TESTS BY ORIFICE METHOD.

2000 cc. of air through the specimen and taking the pressure reading at the 1000 cc. mark. The results were then corrected for the expansion of the air as shown by the volume change curve on the same plot. Two results are indicated here; (a) that the permeability is less at high temperatures, and (b) that it is less for sands containing greater amounts of gas forming materials.

36. Under these conditions of test, as gases are formed in the mold, the air from the permeability machine will not have the opportunity to pass through the sand so readily and the result will be a drop in the permeability. The exact amount of gas passing through the mold is not known however and we thus have no measure of the permeability as it is expressed at normal temperatures.

37. It is safe to say that our present results of permeability tests have produced very little of practical value. Effort could well be spent on the determination of the actual gas volume and pressure in the mold perhaps after the manner of the recent German investigation[3]. Some indication of the maximum allowable gas pressure in a mold to give a sound casting would be helpful. Once this is determined it will be possible to establish the relation between ferrostatic head and allowable mold pressure to prevent "boiling iron". Until such data are available we can merely state that the indicated permeability is lower at high temperatures not because the rate of flow of gas is reduced but because there is more gas to get rid of due to the formation and expansion of gases from the metal and mold material.

SUMMARY

38. In any further study of high temperature effects on molding materials there is considerable information available upon which to base testing procedure. No attempt was made here to include the details of results obtained but as a means of summarizing briefly the important points, Fig. 7 is included. These results were obtained as outlined in this paper and are described in the articles cited in the bibliography.

39. There are a few significant results to be noted from the data plotted in Fig. 7. The first point of interest is the lack of data on strength and permeability at temperatures which are often reached at distances from 0.1 to 0.3 in. from a mold surface. Another point, which from preceding discussion might be expected, is the increase in expansion of sands coming in the same region

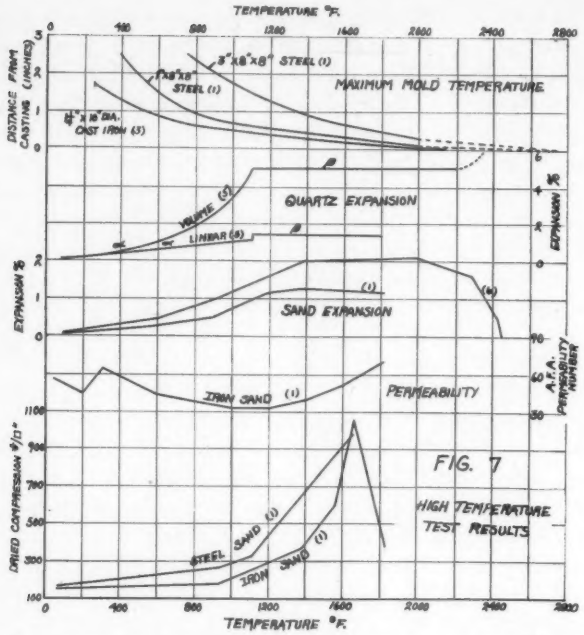

FIG. 7—CURVES OF TEST RESULTS ON SANDS UNDER HIGH TEMPERATURES.

as the increase in expansion of quartz. Considering the rapid increase in quartz expansion above 2200° F. the effect of another factor, possibly clay, is brought out by the opposite effect in the contraction of sands containing clays as bonding materials. From the curves of maximum mold temperatures it is evident that much of the sand reaches points well beyond those discussed as critical in the preceding sections.

CONCLUSIONS AND RECOMMENDATIONS

40. With a problem as full of possibilities as the one being discussed, a fitting conclusion would be merely a listing of suggested projects for future research. In reviewing such a broad subject it is quite possible that some very valuable material has been overlooked unintentionally. This is perhaps more likely among the valuable articles written by men connected with the geology of our refractory materials. The only unfortunate happening was to find that through carelessness or a spirit of unwill-

ingness many test results and procedures were reported without sufficient detail to permit their use in any organized plan of attack on the foundry sand problems confronting us.

41. The following are suggested lines of research which may involve little or much investigation:

a—Data on temperature changes in molds made of different materials and poured in various metals at a number of pouring temperatures.

b—Data on heat transmission of sand mixtures to check work done under (a).

c—Effect of pouring temperature, sand and metal composition, pressure, fluidity, wall thickness, and casting design, on the "burning-on" conditions.

d—Effect of rate of heating on the expansion and contraction of molding sands using rates comparable to the rate of temperature rise in molds as determined in (a).

e—Flowability test apparatus development.

f—Development of mold materials designed specifically for certain strength requirements at high temperatures.

g—Effect of mold conditions on the amount of gaseous material formed at various temperatures.

h—Development of a suitable test similar to a permeability test for high temperature conditions.

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Report of A. F. A. Representative on the Joint Committee on Effects of Phosphorus and Sulphur in Steel*

Members of The American Foundrymen's Association:

As your representative on the Joint Committee on the Effects of Phosphorus and Sulphur in Steel, it has been my duty for the past 14 or 15 years to periodically turn in reports to the A.F.A. on phases of the joint investigation that directly or indirectly were of interest to casting producers.

During the past 3 or 4 years, largely because of the poor business conditions, the Joint Committee has been quite inactive. It has carried on a little work in the way of looking into the correlation of data that had previously been assembled by the Joint Committee, but no actual testing work of any consequence has been done during that period.

During the 15 or 16 years that I have been a member of this Committee, the personnel has not been changed to any considerable extent. Some of the men who were originally appointed on the Committee were not very young at the time of appointment and, of course, they are older now. The condition of what you might call the average age of the Committee personnel (including some individuals who are actually retired from active work), coupled with the existing business conditions, which are not 100 per cent, but materially improved over what they have been, coupled also with the fact that the Committee's objectives in determining the effects of sulphur have been completed within limits that are applicable to actual production, all combined to cause the Joint Committee at a meeting that was held in March, 1936, to ask to be discharged. There does not now seem to be enough commercial interest in determining the bad effects of phosphorus to provide finances to continue that particular work. A report covering this request will formally be made to the sponsoring societies, of which the A.F.A.

* Presented before Steel Division Session at 1936 Convention of A.F.A. in Detroit, Mich.

is one of many. A formal report will be presented at the 1936 Convention of the American Society for Testing Materials.

The job remaining to be done meanwhile is merely the summarizing of all the tentative and other conclusions on sulphur which have been reached periodically by the Joint Committee, and published primarily through the proceedings of the American Society for Testing Materials. The idea was that so many of these conclusions date back so far that a good many individuals who are interested in the subject now, who may not have been interested in it 10 years ago, might like to know what this Committee thinks about the effects of sulphur. It should be mentioned that while the work on the determination of the effects of that element has been very thorough, the Committee really has not much more than scratched the surface in determining the effects of phosphorus. Of course, the purpose originally was to ascertain the harmful effects of the two elements. In the past few years, and particularly the past year, the fact has been made known through the technical press that phosphorus is a very useful alloying element under certain conditions of composition, particularly when low carbon is present. This is a phase of the investigation of phosphorus that was not contemplated in the formation of the Joint Committee.

Probably nothing more need be said on the subject pending the presentation of the formal report of the Joint Committee at the 1936 Convention of the American Society for Testing Materials.

Respectfully submitted,

R. A. BULL,

A.F.A. Representative Joint Committee on The Effects of Phosphorus and Sulphur in Steel.

The Selection of Melting Furnaces for Malleable Iron*

By N. G. GIRSHOVITCH** and A. F. LANDA**

This paper deals with the points that must be taken into consideration when selecting melting equipment for the production of malleable castings. The first section of the paper discusses costs of liquid metal produced by the various melting processes. The authors give comparisons of the various costs involved such as metal charges, capital expenditures, depreciation, auxiliary material, labor and overhead and also discuss furnace melting efficiencies. Physical properties are quoted and in most cases may be compared with American practice but costs are only relative. To give some idea of relative costs in the United States and U.S.S.R., Appendix I has been prepared. The second portion of the paper deals with the quality of metal produced by the various processes and the ease with which these various metals are malleablized. The authors conducted an investigation into the latter question and reached the conclusion that the rotary pulverized-fuel fired furnace produced metal with the highest physical properties and advance the theory that because of the rotation of these furnaces, gases are removed and that these impurities seriously influence properties of malleable iron. The authors also have investigated the graphitization of malleable iron and have found that graphite appears at 1781°F. and much more quickly than was hitherto found. They found that the first stage of graphitization was completed in irons made by certain melting units more quickly than in others and that the same processes which gave quicker first stage graphitization also completed the second stage more quickly than the others. They call attention to the fact that those irons which contain the lowest oxygen contents have the highest physical properties and that the method of operation rather than the type of melting unit is the cause of this variation in properties. The authors also investigated the effect of subcritical temperature cooling and found that the rapidity of this cooling exerts an important influence on the ductility of malleable iron.

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* Presented on behalf of the All-Union Scientific-Engineering Technical Foundrymen's Society, U.S.S.R.

** Foundry Laboratory of the Central Institute of Scientific Research for Machine Building.

NOTE: This paper was presented at a session on Malleable Cast Iron at the 1936 Convention of A.F.A. in Detroit, Mich.

1. A serious and difficult problem, both from the technical and economic points of view, arises in the selection of a melting method for malleable iron. This is due to the great variety of melting equipment available for the manufacture of this material, and includes cupolas, stationary and rotary reverberatory (air) furnaces, electric furnaces with basic and acid linings and the various duplexing processes.

2. The economic expediency of selecting a furnace depends on its efficiency, the cost of fuel, metal charge required for the given unit, auxiliary material, labor, and depreciation, *i.e.*, upon the production cost of the liquid iron produced for the several conditions.

3. The opinion, once held widely by foundrymen, that the method of annealing depends upon the method of melting, has been discarded as a result of experience. Cupola melting, as well as melting by other methods, permits annealing by the American method since plants abroad[1], as well as those in the U.S.S.R.[2], have succeeded in producing low carbon iron (2.2-2.7 per cent carbon) in the cupola sufficiently uniform and superheated to pour any castings and anneal to black-heart malleable iron of sufficiently high mechanical properties. Therefore, the comparison of the economical effect of various melting units is practically limited by the production cost of liquid metal.

COMPARISON OF EFFICIENCY AND COSTS OF MELTING

Furnace Efficiencies

4. Data on the thermal efficiency of various furnaces are given in Table 1. The electric furnace has the greatest efficiency, the duplexing process (using cupola and electric furnace) stands next, followed by the cupola alone, and then cupola combined with the rotary air furnace. With regard to the utilization of fuel, the air furnace is last. If the fact that the production of electric energy has a comparatively low thermal efficiency is taken into consideration, the aspect changes considerably. Depending on conditions, from 1 to 2 kw-hrs. may be produced with 1 kg. (2.2 lb.) of coal. If we take an average figure of 1.5 kw.-hrs., the consumption of fuel and the efficiency of electric furnaces would be illustrated by the figures given in Table 2. Taking into consideration the fuel consumption of generating stations, melting in electric

[1] "DER TEMPERGUSS," 1930, pp. 114-126, also DIE GEISSEREI, 1933, nos. 31, 32.
[2] Russian reference—not translated.

Table 1

EFFICIENCY OF MELTING METHOD

Melting Method		—Air Furnace— Hand-Fired	Air Furnace— Pulverized Fuel	Open-hearth Fce.	—Electric Furnace— Basic	Electric Furnace— Acid	Cupola	Brackelsberg Furnace	Duplexing Process: Cupola Basic	Duplexing Process: Electric Furnace Acid	Duplexing Process: Cupola and Air Fce.	Duplexing Process: Cupola and Rotary Air Fce.
Temperature of Metal.....	°C.	1420	1450	1480	1550	1550	1400	1480	1550	1550	1450	1500
	°F.	2588	2642	2696	2822	2822	2552	2696	2822	2822	2642	2732
Heat Content of 1000 Kg. (2205 lb.) of Metal.....	cal.	244,000	250,000	256,000	270,000	270,000	240,000	256,000	270,000	270,000	250,000	260,000
Fuel Consumption...	Kg.	450	340	280	.....		140	220	100	100	180	160
	lb.	992	750	617	.....		309	485	220	220	397	353
Electric Energy.....	kw.-hr.	.....			650	650	.....		150	120	.....	
Efficiency.....	Per Cent	7.7	10.5	13.1	48.5	48.5	24.5	16.6	32.6	33.8	20.0	23.2

Table 2

EFFICIENCY OF ELECTRIC MELTING UNITS INCLUDING EFFICIENCY OF CURRENT GENERATION

	Electric Furnace		Duplexing Process	
	Basic	Acid	Basic	Acid
Consumption of Fuel per Ton of Liquid Metal in kw. hrs.....	434	434	200	180
Efficiency, Per Cent.....	9.0	9.0	19.5	21.5

furnaces with cold charging approximates that in the air furnaces, while in the case of liquid charging, it ranges between the Brackelsburg furnace and the cupola.

Fuel Costs

5. The total cost of fuel per ton of liquid iron varies considerably according to prices for fuel and electric energy. Taking the price fluctuations per ton in U.S.S.R. at 30 to 50 rubles† for coke, 20 to 40 rubles for coal, 25 to 45 rubles for pulverized fuel, and 3 to 13 kopecks for electric energy per kw.-hr., the data in Table 3 show the relative fuel costs for the various processes. In this manner, all melting methods may compete with regard to fuel cost, but the cupola, and its combinations with other furnaces, is always preferable with regard to economy. However, the combination of the cupola with the electric furnace is profitable only in the case of very low costs of electric energy.

6. The production costs of liquid metal by the various processes cannot be compared solely on the basis of fuel cost. The cost of metal charge also is important and depends upon the melting process, since the various processes differ with regard to the

† For a comparison of relative costs of materials in Amercan currency, see Appendix I.

Table 3

COST OF FUEL FOR MELTING MALLEABLE IRON IN DIFFERENT FURNACES

	Air Furnace		Open-hearth Fce.	Electric Furnace		Cupola	Brackelsberg Fce.	Duplexing Process			
	Hand-Fired	Pulverized Fuel		Basic	Acid			Cupola Basic	Cupola and Electric Fce. Acid	Cupola and Air Fce.	Cupola and Rotary Oil Fce.
Minimum Cost in Rubles of Fuel per Ton of Liquid Metal.....	9.00	8.50	7.50	19.50	19.50	4.20	5.50	7.50	6.60	5.00	4.60
Maximum Cost in Rubles of Fuel per Ton of Liquid Metal.....	18.00	15.30	11.25	85.00	85.00	7.00	10.00	24.50	20.60	8.20	7.40

Table 4

RELATIVE COST OF METAL CHARGE FOR DIFFERENT MELTING FURNACES

	Air or open-hearth Furnace	Electric Fce. Basic	Electric Fce. Acid	Cupola	Brackelsberg Furnace	Duplexing Process: Basic Electric Fce.	Duplexing Process: Acid Electric Fce.	Duplexing Process: Air Furnace
1. Gain or Loss of Elements:								
Carbon, Per Cent	—20	+50	+50	+20	—20	+45	+45	+35
Silicon, Per Cent	—30	—10	—10	—35	—25	—45	—30	—40
Manganese, Per Cent	—50	....	—15	—40	—30	—40	—50	—50
2. Total Oxidation Loss, Per Cent.	8	....	....	5	5	5	5	7
3. Composition of charge per ton of liquid metal:								
Pig Iron, No. 2, lb.	1257	....	....	485	1210	....	....	440
Steel Scrap, lb.	....	1003	1038	550	....	972	974	550
Sprues and Scrap, lb.	1102	1102	1100	1100	1100	1100	1100	1100
Blast Furnace Ferrosilicon, lb.	....	99	66	110	....	254	176	154
Spiegel Iron, lb.	22	....	....	65	....	33	110	110
Total, lb.	2391	2204	2204	2310	2310	2360	2360	2354
4. Cost of Metal Charge per Ton of liquid metal with Steel Scrap at 50 rubles per ton	71.1	61.0	57.7	68.5	68.5	68.9	68.2	72.3
5. Cost of Metal Charge per Ton of liquid metal with Steel Scrap at 10 rubles per ton	71.1	69.0	67.1	73.5	68.5	77.3	76.6	77.3

loss of elements, particularly carbon, and this determines the relative content of iron and scrap permissible in a charge, as is shown in Table 4.

Cost of Metal Charges

7. To obtain results which might be further compared, equal quantities of sprue and scrap, amounting to 50 per cent of the weight of the charge, were taken for all processes at the price of 60 rubles per ton and, on the basis of loss data, the charges for melting methods were calculated for a composition of 2.5 per cent carbon and 1.1 per cent silicon. An exception was made in the cupola charges, in which case the charge was calculated for a composition of 2.7 per cent carbon and 1.0 per cent silicon. The manganese varied from 0.3 to 0.5 per cent, according to sulphur content.

8. The charge was made of No. 2 pig iron containing 3.5 per cent carbon, 2.0 per cent silicon and 0.7 per cent manganese at an average price of 70 rubles per ton, with an addition of blast furnace 12 per cent ferrosilicon at 140 rubles, and of spiegel iron with 10 per cent manganese at 120 rubles per ton. The price of steel scrap varied between 50 and 70 rubles, and the cost of a charge has been calculated in Table 4 according to these two figures.

9. The furnace equipment has only a slight influence on the cost of the charge because our prices for steel scrap approach the prices for pig iron. Even when the prices for steel scrap are somewhat lower than those for pig iron, the economy on steel scrap is usually balanced by the excess overhead charges for special high-alloy additions which cannot be dispensed with. The favorable position of the methods involving higher consumption of steel scrap, which existed a few years ago, has now changed owing to the rise of prices for scrap. The lowest cost charge is obtained when melting in electric furnaces, due to small loss in melting and to the use of steel scrap. The advantage of the electric furnace is still greater with cold charging using cast iron or steel borings and turnings.

Capital Expenditure and Depreciation

10. Capital expenditure and depreciation should have due consideration. For purposes of comparison under similar conditions, the number and efficiency of the units were estimated for a foundry with a total output of 15,000 tons of malleable iron per

Table 5

CAPITAL EXPENDITURES AND DEPRECIATION ESTIMATED FOR DIFFERENT MELTING UNITS

	Air Furnace		Open-hearth	Electric Furnace		Cupola	Brackelsberg	Duplexing Process			
	Hand-Fired	Pulverized Fuel	Fce.	Basic	Acid		Furnace	Basic Electric Fce.	Acid Electric Fce.	Air Fce.	Rotary-Oil-fired Fce.
Capacity (Efficiency) in Tons	20	20	15	7	7	8	5	8 and 7	8 and 7	8 and 15	8 and 2
Number of Furnaces for 15,000 Tons of Malleable Iron	7	7	3	7	7	3	9	3 cup. and 2 el. fces.	3 cup. and 2 el. fces.	3 cup. and 2 Air fcs.	3 cup. and 5 Rot.fces
Cost of Furnaces in Thousands Rubles	350	450	600	900	900	75	900	325	325	225	225
Depreciation per ton of Liquid Metal in Rubles	2.3	3.0	4.0	6.0	6.0	0.75	6.7*	2.2	2.2	1.5	1.5

* This is the author's figures. The editor suspects 6.0 was intended.

annum. Table 5 shows that depreciation costs are highest when melting in electric and Brackelsberg furnaces, and lowest when melting in cupolas.

Auxiliary Material, Labor and Overhead

11. The last item in the cost of liquid iron is the expenditure on auxiliary material, labor for the furnace and the melting plant, and overhead charges. The approximate value of these expenses for different melting furnaces is given in Table 6. These figures are highest for melting in electric furnaces with cold or liquid charging and lowest for cupola melting.

Total Costs

12. By adding the separate items, the total cost of one ton of liquid iron from different melting furnaces is obtained; the minimum and maximum figures are given in Table 7. The cupola gives liquid metal at lowest cost. The cost of iron produced by cupola-air furnace duplexing is somewhat higher (about 10 rubles additional cost per ton) and that of cupola and electric furnace duplexing is still higher even with low prices for electric energy, particularly in the case of the basic furnace. The difference increases with the cost of electric energy, reaching 30 rubles per ton of liquid metal and about 70 rubles per ton of output.

13. The costs of melting in air, open-hearth, and Brackelsberg furnaces differ but slightly, ranging in general between the combinations of cupola with air and electric furnaces. The iron with highest cost is naturally the metal melted in an electric furnace with cold charging. Such an installation is economically admissible only with very low cost of electric energy, about 3 kopecks per kw.-hr. With higher costs of electric energy, the cost of liquid metal may increase to nearly twice that of the cupola or the duplexing process.

METHOD OF OPERATION A FACTOR

14. The selection of the equipment for melting malleable iron is determined from the production viewpoint by its suitability for continuous pouring and by its effect upon the quality of malleable iron. All methods may be equally applicable in non-conveyor foundries, whereas furnaces tapping periodically may not be applied to conveyor foundries with continuous pouring. Thus

Table 6

ESTIMATED COST (IN RUBLES) OF AUXILIARY MATERIALS, LABOR, AND OVERHEAD CHARGES OF A MELTING PLANT USING DIFFERENT MELTING METHODS

	Air Furnace		Open-hearth	Electric Furnace		Cupola	Brackelsberg Furnace	Duplexing Process			
	Hand-Fired	Pulverized Fuel	Fce.	Basic	Acid			Basic Electric Fce.	Acid Electric Fce.	Air Fce.	Rotary-Oil-fired Fce.
Fluxes	1.00	1.00	1.00	3.00	2.00	2.00	1.00	6.00	4.00	3.00	3.00
Electrodes	....	....	....	10.00	10.00	....	....	7.50	5.00	....	....
Refractory material	2.50	2.50	4.00	4.00	3.00	1.00	2.00	3.00	2.50	2.50	2.00
Labor	7.00	6.00	6.00	8.00	8.00	4.00	6.00	6.00	6.00	5.00	5.00
Overhead charges (100 percent)	7.00	6.00	6.00	8.00	8.00	4.00	6.00	6.00	6.00	5.00	5.00
Total	17.50	15.50	17.00	33.00	31.00	11.00	15.00	28.50	23.50	15.50	15.00

Table 7

RELATIVE PRODUCTION COST (IN RUBLES) OF 1-TON OF LIQUID MALLEABLE IRON MELTED IN DIFFERENT FURNACES

	Air Furnace		Open-hearth	Electric Furnace		Cupola	Brackelsberg Furnace	Duplexing Process			
	Hand-Fired	Pulverized Fuel	Fce.	Basic	Acid			Electric Fce. Basic	Electric Fce. Acid	Air Fce.	Rotary-Oil-fired Fce.
Minimum cost	100	98	99	120	114	84	95	107	100	94	93
Maximum cost	109	105	103	193	189	92	110	132	124	102	101

the cupola and the duplexing process—cupola with other furnaces—are the most suitable melting methods for conveyor foundries.

15. All other furnaces, such as air, open-hearth, and electric, may be used only with mixers or by keeping the metal in furnaces. These methods require considerable expenditure and consequently have limited application.

QUALITY OF METAL

16. From the point of view of quality of the metal, the influence of the melting equipment may be discussed both with regard to the possibility of obtaining metal uniform in composition and temperature, and to the effect of constant chemical analysis on the quality of metal.

17. It is evident that iron with any content of silicon, manganese and phosphorus within the range necessary for malleable iron (dephosphorization never being used as a rule) may be manufactured in any melting furnace or combination. Doubts may arise with regard to carbon when melting in the cupola, and with regard to sulphur when melting in cupola and by cupola-electric, or cupola-air furnace duplexing.

Carbon Control

18. For the purpose of obtaining low carbon iron, cupola charges at the Stalin Works, Moscow, contain sufficient steel scrap, and an inactive substance containing no carbon (brick charge) is substituted for the coke in the hearth. The latter prevents the scrap from being excessively carburized. For the same purpose, the Lepse Works melt in the cupola with the bottom at the level of the tuyeres. The practice of these works demonstrates the possibility of obtaining iron with any carbon content between 2 and 3 per cent.

Sulphur Control

19. The sulphur content of the iron depends largely upon the character of the melting furnace. The cupola, and cupola-acid electric or cupola-air furnace duplexing give sulphur contents from 0.08 to 0.14 per cent. Duplexing makes it possible to melt in the cupola with low coke consumption and to strive towards low sulphur fuel. When melting in the cupola alone, the coke consumption is somewhat increased owing to the necessary superheating of the metal. With high sulphur coke and when using a relatively large quantity of sprue, the sulphur content may in-

crease to 0.18 or 0.2 per cent and more. Though modern metallurgy has given a reliable method of controlling sulphur by means of establishing the correct balance between it and manganese, nevertheless, excessive sulphur content is not desirable for high duty castings of intricate design from both the mechanical and foundry points of view. Therefore, the cupola should be considered as an unsuitable melting method for such castings. However, the combination of cupola and acid electric furnace may be used to keep the sulphur content within a permissible range of 0.08 to 0.12 per cent.

Superheating

20. The purpose of the foundryman is not confined to obtaining metal of the required composition. The metal must also be properly superheated, not only to avoid misruns, but also because superheating liquid iron improves the quality of castings and facilitates graphitization[3]. In this respect, electric furnaces, combinations of electric furnaces with the cupola, and open-hearth furnaces have the advantage. Air furnaces and air furnaces combined with cupolas are next. Particularly superheated metal is produced in rotary furnaces. The cupola ranges last in this respect. It cannot insure metal with the necessary fluidity for light castings of low carbon content, when distances between the melting and molding departments are great or when transferring metal from ladle to ladle. It is advisable not to decrease the quantity of carbon in cupola melted iron below 2.7 per cent under such conditions.

Uniform Composition

21. To obtain metal of uniform composition is a problem of no less importance. Furnaces with baths of considerable capacity, such as air, open-hearth and electric furnaces, are unquestionably preferable in this respect, as is the combination of electric furnace and cupola, provided the bath is large enough. In the cupola the conditions are much less favorable but with careful working, satisfactory results may be obtained, as has been shown by Stotz,[4] and by the practice at the authors' works. Melting in the cupola should be done with a somewhat lower sum of C+2 Si, to avoid separa-

[3] White, A. E. and Schneidewind, R., *"Effect of Superheat on Annealing of Malleable Iron,"* TRANS. A.F.A., vol. 41, pp. 98-111 (1933).

[4] "DER TEMPERGUSS," 1930, pp. 114-126.

tion of graphite in the hard iron, in the case of possible variations of composition.

22. It has been shown that metal of any composition, uniformity, and temperature necessary, may be obtained from almost any melting equipment, with the exception of the cupola, which has certain evident defects in comparison with other furnaces. Therefore, the choice of a melting method is chiefly confined to the question of the effect which it has on the properties of malleable iron of uniform analysis.

23. We know that malleable irons of identical chemical analysis may have different mechanical properties, and different speeds of graphitization. Foundrymen attribute these differences to the "heredity" of iron. We consider that the cause of this "heredity" lies in the character of graphite in the raw materials, the content of alloy additions, oxygen, gases, submicroscopic inclusions in suspension, and other factors not taken into account and outside of the control of the foundry, including the alterations in the composition of molding materials, the temperature of superheating and pouring, the composition of slag, etc.

24. All these factors, including the composition of slag, are in close relationship with the quantity of oxygen and gases contained in iron, and affect the properties of gray and malleable iron, as has been shown by numerous investigations.[5]

EASE OF ANNEALING

25. The opinion is widespread in America, as well as in Russia, that iron melted in an air furnace is more easily annealed than iron melted in an electric furnace; that iron melted in a basic electric furnace is annealed with greater difficulty than iron melted in an acid furnace. No systematic investigations had been made on this question, and the Foundry Group of the Central Scientific Research Institute of Machine-Building, under the supervision of the authors, undertook to investigate the effect of melting furnaces on the properties of malleable iron.

26. The investigation was to compare only the furnaces most widely used in practice and of greatest importance in the U.S.S.R., namely—(1) cupola, (2) acid electric furnace, (3) basic electric

[5] Ellicott, TRANS. American Electrochemical Society, 1919, page 175, 1922, p. 2.
Piwowarsky and Heinrichs, ARCHIV F. D. EISENH., December 1934, p. 221.
Keil, Mitsche, Legat, ARCHIV. F. D. EISENH., April, 1934, p. 579.
Diepschlag, DIE GIESSEREI, 1929, p. 822.
Diepschlag und Treuheit, DIE GIESSEREI, 1931, p. 75.
Bardenhauer und Reinhardt, MITT AUS DEM KWJ FUER EISEN, 1934, p. 77.
Diepschug und Michalke, DIE GIESSEREI, 1934, p. 493.

furnace, (4) duplexing process—acid, (5) duplexing process—basic, (6) air furnace and (7) Brackelsberg furnace. It was, of course, necessary to exclude the influence of other variables, and to use the same raw materials, to obtain liquid metal of the same composition, to pour it into the same molds at equal temperature and to anneal the test bars under the same conditions.

Materials Used

27. In the authors' investigations, all these conditions were held as constant as possible. For the tests, several cars of foundry iron were made from the same raw materials under the authors' special supervision in the same blast furnace at the Kramatorsky Works. The composition of the iron was as follows:

Tap No.	Si., Per Cent	Mn., Per Cent	P., Per Cent	S., Per Cent
3688	2.82	0.63	0.098	0.014
3689	2.80	0.63	0.098	0.019
4970	1.64	0.59	0.113	0.081

A part of this iron was re-melted in an electric furnace and poured into pigs for the purpose of obtaining white iron with low carbon and silicon content. The composition of these pigs, which in further heats were to replace the sprues usually used, was 2.61 per cent carbon; 1.02 per cent silicon; 0.24 per cent manganese; 0.107 per cent phosphorus; 0.075 per cent sulphur; 0.02 per cent chromium. In addition to the above mentioned pig iron and re-melted pigs, rail ends were also used in the charge. The analysis of the latter was 0.25 per cent carbon and 0.85 per cent manganese. These three materials in different proportions, depending on the character of the melting furnace, were used in all the tests discussed.

28. Considering the different oxidation losses in various processes and the ordinary variations in the composition of the metal obtained during melting in each furnace, an exact agreement of the analyses of metal from all sources could not be expected. Indeed, there is no necessity of this since the widest variations in composition affect but slightly the properties of malleable iron. The following was selected as a desired composition of metal: 2.60 per cent carbon; 1.0 per cent silicon; 0.3 per cent manganese; 0.09 per cent phosphorus; 0.08 per cent sulphur and the calculation of the charge was made accordingly.

Heats Used in Test

29. The sulphur content was selected relatively high in view

of the difficulty of obtaining lower values in the cupola. The analyses of liquid iron obtained in different units are shown in Table 8. As melt No. 1a deviated too far in carbon from the normal analysis and melt No. 2a was of abnormally high silicon content, these two heats were not used in further tests. The remaining heats were considered satisfactory in composition, although the deviations from normal composition were as follows:

Element	Deviation	
	+ Per Cent to	— Per Cent
Carbon	0.18	0.15
Silicon	0.04	0.07
Manganese	0.04	0.09
Sulphur	0.02	0.02

The sulphur content in the metal produced in the air furnace, was abnormally low but this heat was included in our investigations. Other variations in the composition of metal are within the normal range when melting in the same furnace.

Test Specimens

30. All heats were poured into special test specimen molds at the same temperature of about 1360° C. (2462° F.). Specimens were cast from each heat, as follows:

12 Specimens for tension tests.
12 Specimens for cross bending tests.
12 Specimens for impact strength tests.

31. Since metal melted in a basic furnace is less subject to graphitization than metal melted in an acid furnace, and considering that the basic lining should affect only the content of gases,

Table 8

CHEMICAL ANALYSIS OF METAL FROM VARIOUS MELTING UNITS

No.	Melting Method	C %	Si %	Mn %	P %	S %
1.	Cupola	2.75	0.93	0.21	....	0.1
1a.	Cupola	2.92	0.94	0.26	....	0.083
2.	Duplexing Process, Acid	2.69	1.04	0.30	....	0.096
2a.	Duplexing Process, Acid	2.63	1.29	0.31	....	0.09
3.	Duplexing Process, Basic	2.63	1.04	0.28	....	0.067
4.	Electric Furnace, Acid	2.45	1.01	0.23	....	0.071
4a.	Electric Furnace, Acid	2.57	1.01	0.30	....	0.071
5.	Electric Furnace, Basic	2.50	1.04	0.30	....	0.058
6.	Brackelsberg Furnace	2.74	0.94	0.34	0.08	....
7.	Air Furnace	2.78	1.01	0.26	0.09	0.018

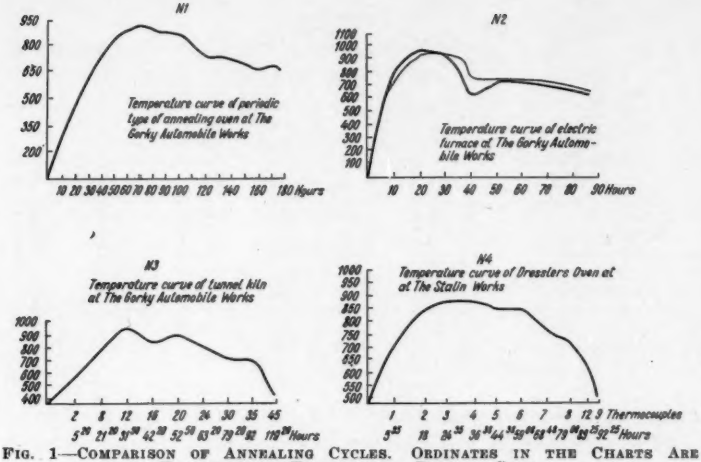
N1
Temperature curve of periodic type of annealing oven at The Gorky Automobile Works
N2
Temperature curve of electric furnace at The Gorky Automobile Works
N3
Temperature curve of tunnel kiln at The Gorky Automobile Works
N4
Temperature curve of Dressiers Oven at The Stalin Works
Hours
Thermocouples

FIG. 1—COMPARISON OF ANNEALING CYCLES. ORDINATES IN THE CHARTS ARE TEMPERATURES EXPRESSED IN DEGREES CENT.

oxygen, and non-metallic inclusions in the metal, further portions of metal were taken for melting in the basic electric furnace and for basic duplexing, and, after adding aluminum in the ladle (0.02 per cent), were poured into additional molds. For comparison purposes, the same was done with heat No. 4 from the acid furnace.

Annealing Test Bars

32. All these bars, lots of three for each sample and each furnace, were annealed (1) in an oven of periodic type at the Gorky Automobile Works, (2) in an electric furnace at the same works, and (3) in 2 tunnel kilns at the Stalin Works, and the Luberetzki Works, in accordance with cycles shown in Fig. 1. After annealing, the bars were subjected to mechanical tests and average results are shown in Table 9.

33. It seems that melting equipment has a very slight effect on the properties of malleable iron. For instance, there is no difference in the properties of malleable iron produced by the cupola and the acid duplexing process, either in tensile strength, or ductility. Malleable iron obtained by the acid duplexing process also does not differ in properties from iron obtained by basic duplexing. The properties of metal from the acid electric furnace with cold charging are very close to those mentioned in Table 9. Samples from a basic electric furnace, cold charged, have considerably lower mechanical properties, especially with regard to tensile

Table 9

EFFECT OF MELTING METHOD UPON MECHANICAL PROPERTIES OF MALLEABLE IRON

(Average for 12 tests)

No.	Melting Method	Tensile Strength		Elongation Per Cent	Bending* in Degrees	Impact* Strength Kg/cm²	Brinell Hardness
		Kg/mm²	Lbs. per Sq. In.				
1.	Cupola	32.4	46,000	7.9	51.25	5.8	121.9
2.	Duplexing, Acid	31.3	44,500	7.4	42.45	6.0	126.2
3.	Duplexing, Basic	32.0	45,500	7.2	54.45	5.1	125.0
4.	Electric Furnace, Acid, with Cold Charging	33.1	47,100	6.3	59.25	4.8	129.0
5.	Electric Furnace, Basic	27.9	39,700	5.5	64.83	4.1	119.7
6.	Brackelsberg Furnace	34.2	48,600	10.1	63.50	8.8	123.1
7.	Air Furnace	30.6	43,500	9.6	66.25	8.2	112.8

*Form and dimension of Test Specimen not given.

strength, as is seen from Table 9. Length of melting time in an electric furnace with basic bottom and cold charging has probably contributed to the oxidation of metal and its saturation with gases which evidently produced the decrease of mechanical properties.

34. This example, however, is in no way against the use of the basic furnace as a melting unit, but only against the method of melting adopted in this particular case. Melting in a stationary reverberatory furnace, and especially in a rotary reverberatory furnace, evidently improves the properties of malleable iron. In the first case, an increase in ductility of the material (elongation, impact, strength) is noted and in the second case, a still greater ductility with simultaneous increase of impact strength. Thus the best properties were shown by test bars melted in the Brackelsberg furnace, which is confirmed by the literature.

Results of Tests

35. The evident advantage of malleable iron melted in the Brackelsberg furnace is seen not only from the average figures of Table 9 but also from the comparison of maximum figures of all melts, shown in Table 10. Here also, metal melted in the Brackelsberg furnace gives maximum figures for tensile strength, corresponding to maximum figures for ductility. The conclusion becomes still more striking since the analyses of metal obtained in the air furnace and in the Brackelsberg furnace show a relatively high carbon content (Table 8), and consequently, it may be presumed that in the case of lower carbon content the results would be even more evident.

36. The superior quality of malleable iron melted in the

Table 10

EFFECT OF MELTING EQUIPMENT ON MECHANICAL PROPERTIES OF MALLEABLE IRON

(MAXIMUM FIGURES FOR TENSILE STRENGTH, IMPACT STRENGTH, ELONGATION, BENDING ANGLE, AND MINIMUM FIGURES FOR HARDNESS)

No.	Melting Unit	Electric Annealing Furnace—Gorky Automobile Works						Periodic Annealing Oven—Gorky Automobile Works					
		Tensile Strength		Elongation,	Bending Angle*,	Impact Strength*,	Brinell	Tensile Strength		Elongation,	Bending Angle*,	Impact Strength*,	Brinell
		kg./mm²	lb./in²	Per Cent	Degrees	kg./m/cm²	Hardness	kg./mm²	lb./in.²	Per Cent	Degrees	kg./m/cm²	Hardness
1.	Cupola	30.0	42,660	9.0	63.25	6.9	116	33.8	48,060	11.8	82.00	9.6	114
2.	Duplexing, Acid	31.0	44,080	8.6	40.00	7.7	126	32.8	46,640	10.6	67.00	8.1	116
3.	Duplexing, Basic	31.9	45,360	10.2	58.25	6.9	121	35.0	49,770	13.0	79.50	7.3	114
4.	Electric Furnace, Acid	35.4	50,340	9.0	78.00	11.0	116	31.6	44,930	12.0	153.50	10.8	112
5.	Electric Furnace, Basic	34.6	49,200	12.6	66.00	6.9	116	28.7	40,810	6.4	134.00	8.3	112
6.	Brackelsberg Furnace	35.4	50,340	13.6	84.75	10.2	121	35.1	49,910	18.5	61.25	6.4	126
7.	Reverberatory (Air) Furnace	30.2	42,940	12.8	92.50	9.4	112	29.7	42,230	9.9	93.50	9.2	105

No.	Melting Unit	Tunnel Kiln—Stalin Works						Tunnel Kiln—Lubertsi State Works					
		Tensile Strength		Elongation,	Bending Angle,*	Impact Strength,*	Brinell	Tensile Strength		Elongation,	Bending Angle,*	Impact Strength,*	Brinell
		kg./mm²	lb./in.²	Per Cent	Degrees	kg./m/cm²	Hardness	kg./mm²	lb./in.²	Per Cent	Degrees	kg./m/cm²	Hardness
1.	Cupola	35.3	50,200	12.6	37.00	6.2	121	33.7	47,920	6.4	57.00	5.3	124
2.	Duplexing, Acid	33.8	48,060	8.4	40.50	6.4	128	30.5	43,370	6.2	45.00	7.4	128
3.	Duplexing, Basic	34.4	48,920	8.6	52.00	8.2	124	35.0	49,770	9.0	58.00	5.3	121
4.	Electric Furnace, Acid	38.1	54,180	8.8	53.25	5.4	118	39.9	56,740	8.8	65.00	6.9	114
5.	Electric Furnace, Basic	34.3	48,770	8.8	57.00	6.4	116	31.6	44,930	4.2	78.00	6.4	116
6.	Brackelsberg Furnace	37.7	53,610	13.6	64.75	10.8	118	37.3	53,040	8.6	78.00	11.1	116
7.	Reverberatory (Air) Furnace	31.9	45,260	9.8	54.00	9.6	107	29.5	41,950	7.4	62.50	9.0	105

*Form and dimensions of Test Specimen not given.

Brackelsberg furnace might be expected theoretically, since metal obtained by this method of melting should have minimum content of gases and oxygen, owing to the continuous rotation of the furnace. Our heats gave the results of Table 11 with regard to the percentage of oxygen. This minimum content of oxygen in the metal obtained from the Brackelsberg furnace corresponds to the higher mechanical properties of the metal. The highest oxygen content in metal melted in the basic electric furnace with cold charging is also in perfect agreement with the rather inferior properties of the metal (Table 9). The lower oxygen content in the metal melted by basic duplexing process, when compared to the

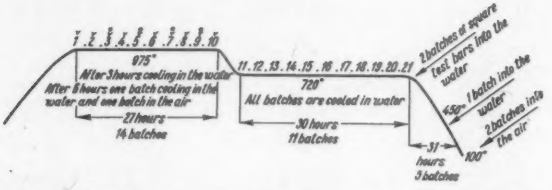
1 2 3 4 5 6 7 8 9 10
975°
After 3 hours cooling in the water
After 6 hours one batch cooling in the water and one batch in the air
27 hours
14 batches
11 12 13 14 15 16 17 18 19 20 21
720°
All batches are cooled in water
30 hours
11 batches
31 hours
3 batches
100°
2 batches of square test bars into the water
1 batch into the water
2 batches into the air

FIG. 2—ANNEALING CYCLE FOR SMALL TEST BARS IN LABORATORY FURNACE. THIS CHART SHOWS THE RELATIVE TIMES, TEMPERATURES AND RATES OF HEATING AND COOLING.

acid duplexing process, shows that the oxidation of the metal has been caused by the method of carrying out the melting operation rather than by the character of the lining. Therefore, the possibility of obtaining different results with different methods of melting is not excluded. Moreover, under certain conditions, higher oxidation of metal in a basic furnace is quite possible, owing to penetration of basic slag into the metal and to the deoxidation of metal by acid slags in the acid furnace.

Table 11

OXYGEN CONTENT IN METAL OBTAINED FROM DIFFERENT MELTING UNITS

Melting Unit	Oxygen Per Cent
Brackelsberg Furnace	0.0020
Reverberatory Furnace	....
Cupola	0.0025
Duplexing, Basic	0.0026
Duplexing, Acid	0.0033
Electric Furnace, Acid	0.0050
Electric Furnace, Basic	0.0054

INVESTIGATE GRAPHITIZATION

37. Simultaneously with annealing under shop conditions. special small test bars were placed in a small electric furnace of laboratory type and were subjected to annealing according to the curves of Fig. 2. When the temperature of 975° C. (1787° F.) was reached, a batch of test bars containing one test bar cast from metal from each melting furnace was taken out and quenched in water. A new batch was subsequently taken but every 3 hours. After quenching in water, all test bars were examined under the microscope to determine structural components and the moment of attaining stable equilibrium. A supplementary batch of test bars was taken out every 6 hours, and, upon cooling in the air, was also subjected to microscopic examination. After annealing at 975° C. (1787° F.) for 27 hours, the test bars remaining in the furnace were cooled to 720° C. (1328° F.) and held at that temperature 30 hours for the carrying out of the second stage of graphitization.

38. During this period of annealing, a batch of test bars was also taken every 3 hours, and, upon cooling in water, was examined under the microscope for determining the structural components and the moment of completion of the second stage of graphitization. These latter bars also were tested for Brinell hardness. The examination of the central part of the bars under the microscope helps to understand the effects of melting method upon rate of cementite decomposition and the reaching of stable equilibrium (Table 12).

39. Graphitization was followed by inspecting the central part of the cross section because decarburization at the rim of the test bars somewhat distorts the normal conditions. As is seen from Table 12, the system consisting of austenite and cementite gradually changes into the stable state, austenite—graphite. The appearance of graphite occurs immediately the temperature of annealing has reached 975° C. (1787° F.) and it happens more quickly than it has been found in the investigations of Schütz[6].

40. The condition of stable equilibrium, as can be seen from Table 12, is reached rather quickly, and after 9 hours annealing at 975° C. (1787° F.), it is reached for all test bars independently of the melting equipment from which the metal was obtained. Thus, the prolonged period of annealing to which malleable iron castings are usually subjected in practice is mostly superfluous and

[6] Schütz-Stotz, "DER TEMPERGUSS," 1930, p. 57.

Table 12

EFFECT OF MELTING METHOD OF THE RATE OF REACHING STABLE EQUILIBRIUM

Time of taking the Test—hours	Cupola	Duplexing, Acid	Duplexing, Basic	Electric Furnace, Acid	Electric Furnace, Basic	Brackelsberg Furnace	Reverberatory Furnace
First stage 975° C. (1787° F.)	L+C+G*	L+C+G	L+C+G	L+C+G	L+C+G	L+C+G	L+C+G
First stage 3	P+C+G*	P+C+G	P+G	P+C+G	P+C+G	P+G	P+G
First stage 6	P+C+G*	P+G	P+G	P+G	P+C+G	P+G	P+G
First stage 9	P+G	P+G	P+G	P+G	P+G	P+G	P+G
First stage 12	P+G	P+G	P+G	P+G	P+G	P+G	P+G
First stage 15	P+G	P+G	P+G	P+G	P+G	P+G	P+G
First stage 18	P+G	P+G	P+G	P+G	P+G	P+G	P+G
First stage 21	P+G	P+G	P+G	P+G	P+G	P+G	P+G
First stage 24	P+G	P+G	P+G	P+G	P+G	P+G	P+G

*L—Ledeburite, C—Cementite, F—Ferrite, P—Pearlite, G—Graphite (Temper Carbon).

Table 13

EFFECT OF MELTING METHOD UPON THE RATE OF COMPLETION OF THE SECOND STAGE OF GRAPHITIZATION

Time of taking the Test—hours	Cupola	Duplexing, Acid	Duplexing, Basic	Electric Furnace, Acid	Electric Furnace, Basic	Brackelsberg Furnace	Reverberatory Furnace
Second stage at 720° C. (1328° F.)	F+P+G*	F+P+G	F+P+G	F+P+G	F+P+G	F+P+G	F+P+G
Second stage at 3	F+P+G*	F+P+G	F+P+G	F+P+G	F+P+G	F+P+G	F+P+G
Second stage at 6	F+P+G*	F+P+G	F+P+G	F+P+G	F+P+G	F+P+G	F+P+G
Second stage at 9	F+P+G*	F+P+G	F+P+G	F+P+G	F+P+G	F+P+G	F+P+G
Second stage at 12	F+P+G*	F+P+G	F+P+G	F+P+G	F+P+G	F+P+G	F+P+G
Second stage at 15	F+P+G*	F+P+G	F+P+G	F+P+G	F+P+G	F+G	F+G
Second stage at 18	F+P+G*	F+P+G	F+P+G	F+P+G	F+P+G	F+G	F+G
Second stage at 21	F+P+G*	F+P+G	F+P+G	F+G	F+P+G	F+G	F+G

*Ferrite, P—Pearlite, G—Graphite (Temper Carbon).

the first stage of graphitization may be completed in a considerably shorter time than is practiced.

First Stage Graphitization

41. The absolute time necessary for the completion of the first stage of graphitization obtained in our experiments is rather near to the time which White and Schneidewind[7] obtained in their investigations; they had determined that at 1 per cent silicon, 10 hours are necessary for reaching the equilibrium 925° C. (1697° F.). It is natural that at the still higher temperature which the authors selected, stable equilibrium was reached in even a shorter time.

42. Comparing the time necessary for decomposition of primary cementite in the test bars poured from metal obtained from different melting furnaces (Table 12), it is seen that this time varies from 3 to 9 hours, and that the shortest time necessary was for the test bars poured from metal obtained from the reverberatory and Brackelsberg furnaces and by basic duplexing. In these test specimens, primary cementite decomposed in 3 hours. The longest time was necessary for the test bars composed of metal taken from the basic electric furnace and the cupola. These specimens required 9 hours for decomposition of the primary cementite.

Second Stage Graphitization

43. The second stage of graphitization (Table 13) was completed with greatest speed in test bars from the metal taken from the reverberatory and Brackelsberg furnaces, in which cases it was completed in 15 hours annealing at 720° C. (1328° F.). It might be supposed that the greater rate of graphitization was caused, in this case, by the somewhat higher carbon content. However, the behavior of the test bars poured from the cupola iron with the same carbon content refutes this assumption. Table 14 gives data for the hardness of the test bars during the second stage of graphitization. Although the hardness depends not only upon the quantity of combined carbon but also upon the character of pearlite (lamellar, granular, etc.), the average figures of Table 14 for hardness may nevertheless give a certain idea of the rate of disintegration of eutectoid cementite.

44. These data, completely corresponding to the data of Table 13, show once more that the minimum average hardness,

[7] White, A. E., and Schneidewind, R., *"The Metallurgy of Malleabilization,"* TRANS. A.F.A., vol. 40, pp. 88-117 (1932).

Table 14

EFFECT OF MELTING UNITS UPON THE HARDNESS OF MALLEABLE IRON

Time of taking the Test—hours	Cupola	Duplexing, Acid	Duplexing, Basic	Electric Furnace, Acid	Electric Furnace, Basic	Brackelsberg Furnace	Reverberatory Furnace
Second stage at 720° C. (1328° F.)....	321	286	183	302	321	255	241
Second stage at 3.....	187	196	156	187	196	...	143
Second stage at 6.....	156	174	134	149	170	166	121
Second stage at 9.....	156	183	179	166	170	143	124
Second stage at 12.....	131	170	128	193	...	...	116
Second stage at 15.....	149	170	170	156	179	137	121
Second stage at 18.....	146	149	156	149	149	137	112
Second stage at 21.....	131	149	126	131	137	149	121
Average Hardness.....	172	184	154	173	189	164	137

*Form and dimension of Test Specimen not given.

and consequently the greatest rate of disintegration of pearlite, was shown by the test bars poured from iron from the reverberatory and Brackelsberg furnaces and that obtained by basic duplexing. Test bars from the basic electric furnace showed the greatest hardness, corresponding to the data in Tables 12 and 13.

EFFECT OF OXYGEN ON GRAPHITIZATION

45. When the results from Tables 12, 13 and 14 are compared with the data of oxygen content from Table 11, it will be easily seen that the oxidation of metal corresponds to the rate of graphitization of malleable iron. The higher the oxygen content in the metal, the longer the period of time required for the completion of the first and second stages of graphitization. This is confirmed by data given in Table 15, showing that deoxidation of metal by aluminum reduces the hardness of malleable iron and accelerates graphitization.

46. *Thus it may be presumed that the effect of melting method is determined by the content of gases and oxygen with which the metal is saturated during the process, and therefore, the rate of graphitization and the mechanical properties of malleable iron depend upon the correct operation of the melting process more than upon the type of furnace.* A typical demonstration of this statement is given in Table 16, showing figures for hardness of two heats from the same acid electric furnace. Though the chemical analyses of the metal are identical, the graphitization of the second heat is apparently slower, owing to considerable saturation with gases and oxygen.

EFFECT OF RATE OF COOLING ON DUCTILITY

47. Fig. 2 shows that five batches of test bars, after holding at 720° C. (1328° F.) for 30 hours, were cooled by different methods to determine the effect of the rate of cooling in the interval of subcritical temperature upon the properties of malleable iron and its liability to give white fracture.

48. American malleable iron, when rapidly cooled at 450-500° C. (842-932° F.) sometimes gives a white fracture with consequent considerable decrease of ductility. This liability to produce a white fracture disappears if rapid cooling from 650° C. (1202° F.) is adopted, as has been shown by Kikuta[8]. In this case, no

[8] Kikuta, Tario, *"Thermal Treatment of Black-heart Malleable Iron,"* TRANS. A.F.A., vol. 40, p. 401 (1932).

Table 15

EFFECT OF DEOXIDATION OF LIQUID METAL BY ALUMINUM ON THE HARDNESS OF MALLEABLE IRON

Melting Unit	Annealing Time at 720° C. (1328° F.) (hours)								Average* hardness
	0	3	6	9	12	15	18	21	
Duplexing Basic	183	156	134	179	128	170	156	126	154
Duplexing + Al	...	...	...	137	151	156	...	...	150
Electric Furnace, Basic	321	196	170	170	...	179	149	137	189
Electric Furnace + Al	311	...	149	137	143	137	131	149	174
Electric Furnace, Acid	302	187	149	166	143	156	149	131	173
Electric Furnace + Al	332	170	143	131	126	126	126	128	160
Average without Al	268	180	151	172	135	168	151	131	172
Average + Al	275	174	142	135	128	140	138	134	160

*In calculating the averages, the hardness of missing samples with the addition of Aluminum was taken as equal to the hardness of corresponding samples with aluminum.

Table 16

RELATIVE HARDNESS OF MALLEABLE IRON OF IDENTICAL COMPOSITION FROM TWO HEATS IN ACID FURNACE

(Same Treatments as Table 15)

Analysis of Metal percentage)	Annealing cycle at 720° C. (1328° F.) (hours)								Average hardness
	0	3	6	9	12	15	18	21	
2.45 —C 1.01 —Si 0.23 —Mn 0.071 —S	302	187	149	166	143	156	149	131	173
2.57 —C 1.01 —Si 0.3 —Mn 0.071 —S	321	207	187	187	187	187	179	166	200

white fracture appears even with subsequent heating of the castings to 450° C. (842° F.), followed by rapid cooling.

49. For the purpose of verifying the deductions of Kikuta, and ascertaining the effect of melting methods in this direction, five batches of test bars were tested (one test bar from each melting method in every batch). The first batch was quenched in water after 30 hours annealing at 720° C. (1328° F.). The second batch, after a similar quenching in water, was heated to 450° C. (842° F.) with subsequent rapid cooling in water. The third batch was slowly cooled in the oven at the rate of 20° C. (36° F.) per hour from 720° C. (1328° F.) to 450° C. (842° F.) with subsequent quenching in water. The fourth batch was slowly cooled to 100° C. (212° F.) and the fifth batch after a slow and complete cooling, was heated to 450° C. (842° F.) with subsequent quenching in water. All the above test bars were tested for impact strength

Table 17

EFFECT OF MELTING METHOD ON THE FORMATION OF WHITE FRACTURE.

Method of Cooling	Properties	Cupola	—Duplexing Process— Acid	Basic	Electric Furnace, Acid	Electric Furnace, Basic	Brackelsberg Furnace	Air Furnace	Average
Quenching in water at 720° C. (1328° F.).....	Impact strength* kg.-m/cm².....	10	12.2	9.4	7.3	4.4	25	18.9	12.5
	Hardness (Brinell)	137	170	153	149	143	131	143	147
	Fracture.....	black plus white	white	white	black plus white	black plus white	black	black	....
	Structure.....	F+P+G	F+P+G	F+P+G	F+P+G	F+P+G	F+G	F+G	....
Quenching in water at 720° C. (1328° F), with subsequent heating to 450° C. (842° F.) and quenching in water....	Impact strength* kg.-m/cm².....	....	7.5	11	....	3	22.8	19.6	12.4
	Hardness (Brinell)	....	149	143	....	156	131	103	138
	Fracture.....	....	white	black	....	white	black	black	....
	Structure.....	....	F+P+G	F+G	....	F+P+G	F+G	F+G	....
Slow cooling at the rate of 20° C. (36° F.) per hour from 720° to 450° C. (1328° to 842° F.), with subsequent quenching in water....	Impact strength* kg.-m/cm².....	9.0	20	12.5	27.5	3.4	26.2	26.5	16.9
	Hardness (Brinell)	143	137	137	128.0	149	107	131	133
	Fracture.....	white	black plus white	black	black plus white	white	black	black	....
	Structure.....	F+P+G	F+P+G	F+G	F+P+G	F+P+G	F+G	F+G	....
Slow cooling at the rate of 20° C. (36° F.) per hour from 720° C. to 100° C. (1328° to 212° F.).....	Impact strength* kg.-m/cm².....	15.5	16.5	11.5	17.7	7.7	30	29	18.2
	Hardness (Brinell)	137	....	126	126	134	126	107	126
	Fracture.....	white	....	white	black plus white	white	black	black	....
	Structure.....	F+P+G	....	F+P+G	F+P+G	F+P+G	F+G	F+G	....
Slow cooling at rate of 20° C. (36° F.) per hour from 720° C. (1328° F.) to 100° C. (212° F.), with subsequent heating to 450° C (842° F.) and quenching in water.....	Impact strength* kg.-m/cm².....	19.5	16.8	11.9	25.9	17.4	19.1	....	18.4
	Hardness (Brinell)	143	137	126	131	137	121	....	133
	Fracture.....	black plus white	black plus white	black plus white	black plus white	white	black	....	....
	Structure.....	F+P+G	F+P+G	F+G	F+P+G	F+P+G	F+G	....	....

*Dimensions and form of test specimen not given.

(unnotched specimens) hardness, and microstructure and the results are given in Table 17.

50. *Table 17 shows that quenching in water 450° C. (842° F.) does not affect in any way the brittleness of malleable iron, irrespective of the previous rate of cooling from 720° C. (1328° F.).* Thus the observations of Kikuta were not confirmed by our experiments, and the formation of white fracture is conditioned by some additional factors. At the same time, the data of Table 17 show, contrary to the prevailing opinion, that *the rapidity of cooling in the interval of subcritical temperature exercises a considerable influence on the ductility of malleable iron.*

51. Thus, for instance, with rapid cooling from 720° C. (1328° F.), samples of malleable iron in the tests showed an average impact strength of 12.5 kg-m/cm², whereas with slow cooling the impact strength increased almost 50 per cent, *i. e.*, to 18.4 kg-m/cm². Slow cooling to 450° C. (842° F.) with subsequent quenching in water, gave an average of 16.9 kg-m/cm² for impact strength.

52. It is possible that the effect of slow cooling at subcritical temperature may be related to the precipitation of carbon from the solid solution in the ferrite on the lowering of temperature. Subsequent heating in Fe-alpha region, and rapid cooling does not alter the high ductility of the metal, as may be seen from Table 17. The cause is that the process of precipitation of free carbon into solution is very slow at low temperatures even in Fe-alpha region, and consequently free carbon dissolves with difficulty in Fe-alpha region.

53. Examining Table 17 from the point of view of the effect of melting equipment, the exceptional quality of samples melted in the Brackelsberg and the air furnaces, and the inferior quality of the samples from the basic electric furnace can be noted. Thus, taking into consideration the data of Table 11, the interdependence of brittleness, white fracture, and the content of gases and oxygen in malleable iron may be determined in this case as well. The considerable increase of ductility after the deoxidation of metal is easily accounted for, as is shown in Table 18. Thus, the oxidized metal contributes to the formation of white fracture with corresponding decrease of impact strength due to the inclusion of pearlite, distributed generally in a net-work along the boundaries of ferrite grains.

54. The oxidation of metal, and the content of gases is cer-

Table 18

EFFECT OF DEOXIDATION OF METAL ON THE FORMATION OF WHITE FRACTURE

Method of Cooling	Properties	Without Addition of Aluminum: Duplexing, Basic	Without Addition of Aluminum: Electric Furnace, Basic	Without Addition of Aluminum: Electric Furnace, Acid	Without Addition of Aluminum: Average	With Addition of Aluminum: Duplexing, Basic	With Addition of Aluminum: Electric Furnace, Basic	With Addition of Aluminum: Electric Furnace, Acid	With Addition of Aluminum: Average
Quenching in water at 720° C. (1328° F.).....	Impact strength* kg.-m/cm².....	9.4	4.4	7.3	7.0	3.9	18.1	16.9	13.0
	Hardness (Brinell)	153	143	149	148	156	149	143	149
	Fracture.....	white	black plus white	black plus white	....	white	black plus white	black plus white	....
	Structure.....	F+P+G	F+P+G	F+P+G	....	F+P+G	F+G	F+P+G	....
Quenching in water at 720° C. (1328° F.), with subsequent heating to 450° C. (842° F.) and quenching in water....	Impact strength* kg.-m/cm².....	11	3	....	7.0	4.5	15.6	17.8	12.6
	Hardness (Brinell)	143	156	....	150	143	137	131	137
	Fracture.....	black	white	....	....	black plus white	black	black	....
	Structure.....	F+G	F+P+G	....	....	F+P+G	F+G	F+P+G	....
Slow cooling at the rate of 20° C. per hour from 720° to 450° C. (1328° to 842° F.), with subsequent quenching in water.....	Impact strength* kg.-m/cm².....	12.5	3.4	27.5	14.4	18	28.5	11.9	19.7
	Hardness (Brinell)	137	149	128	138	137	131	128	132
	Fracture.....	black	white	black plus white	....	black plus white	black	black plus white	....
	Structure.....	F+G	F+P+G	F+P+G	....	F+G	F+P+G	F+P+G	....
Slow cooling at the rate of 20° C. per hour from 720° to 100° C. (1328° to 212° F).....	Impact strength* kg.-m/cm².....	11.5	7.7	17.7	12.3	26.4	17.7	8.5	17.5
	Hardness (Brinell)	126	134	126	129	103	121	143	122
	Fracture.....	white	white	black plus white	....	black plus white	black plus white	white	....
	Structure.....	F+P+G	F+P+G	F+P+G	....	F+P	F+P+G	F+P+G	....
Slow cooling at the rate of 20° C. (36° F.) per hour from 720° to 100° C. (1328° to 212° F.), with subsequent heating to 450° C. (842° F.) and quenching in water	Impact strength* kg.-m/cm².....	11.9	25.9	25.9	21.2	21.6	21.9	20.4	21.3
	Hardness (Brinell)	126	131	131	129	137	121	126	128
	Fracture.....	black plus white	black plus white	black plus white	....	black plus white	black plus white	black plus white	....
	Structure.....	F+G	F+P+G	F+P+G	....	F+G	F+G	F+P+G	....

*Dimensions and form of test specimen not given.

tainly a result of the method of melting, and of the character of raw materials. With all other conditions being equal, oxidation and gas content are undoubtedly a function expressing the character of melting method. Therefore, the latter affects to a certain extent the properties of malleable iron, and the time necessary for its graphitization. Thus it is quite evident that perfection in the annealing process and the certainty of obtaining malleable iron of desired properties without great variations, may be attained only on the basis of regular control of melting. This control must not be confined to the content of carbon, silicon, manganese, sulphur, phosphorous, and chromium, but should also include the content of oxygen and the quantity of gases; then it would be possible to control the content of these gases in malleable iron to the same extent to which, at present, the content of the ordinary elements is controlled.

CONCLUSIONS

55. The following conclusions may be drawn from these investigations:

(1) Investigations on the effect of type of melting unit on the properties and the rate of graphitization of malleable iron have shown the evident advantage of the rotary Brackelsberg furnace. The poorest results were obtained when melting in the basic electric furnace with cold charging.

(2) The effect of melting in any of the furnaces—cupola, basic and acid duplexing process, air furnace and acid electric furnace—is comparatively small, and probably depends upon the method of executing the process. The opinion mentioned in literature, that the graphitization of malleable iron melted by basic duplexing process is slower than the material obtained by other processes, was not confirmed by the authors' tests.

(3) The effect of type of melting furnace upon the mechanical properties and the rate of graphitization of malleable iron is determined chiefly by the quantity of oxygen and gases in the metal.

(4) The quantity of oxygen and gases in the metal is determined not only by the character of the equipment but chiefly by the method of carrying on the process in a given furnace.

(5) A decrease in oxides and gases in the metal leads,

in the opinion of the authors, to an increase of strength and ductility of the metal.

(6) The time necessary for the first stage of graphitization is considerably shorter than the time used in practice, and even under the least favorable conditions should not exceed 10 hours at 975° C. (1787° F.).

(7) The rate of graphitization in the first and second stages probably depends upon the content of oxides and gases in the metal, an increase of this content decreasing the rate of graphitization.

(8) Slow cooling of malleable iron castings in the subcritical temperature interval contributes to increased ductility of the metal.

(9) Brittleness and white fracture in malleable iron are related to the content of oxides and gases in the metal, which causes and facilitates this phenomenon.

(10) Deoxidation of metal diminishes its liability to white fracture and increases the ductility of malleable iron.

(11) To attain final improvement of the manufacturing of malleable iron and to secure constant standard qualities, it is necessary to introduce into practice the control of oxygen and gas content in malleable iron.

(12) The effect of oxygen and gases in malleable iron should be made an object of special investigation.

(13) With regard to the temperature of liquid metal, all melting units may be divided into 3 groups:—electric furnaces, air furnaces, and cupolas.

(14) Malleable iron of lowest cost is obtained by melting in the cupola. The following is sequence with regard to production cost: (1) combination of cupola with air furnaces, (2) air furnaces and open-hearth furnaces, (3) duplexing process—cupola and electric furnace, (4) the cost is highest for malleable iron melted in electric furnaces with cold charging.

(15) Small changes in the order of the sequence scheme given in (14) are possible with fluctuations in prices for steel scrap, pig iron, fuel, and electric energy.

(16) On the basis of economic analysis and investigation work effected by the Central Institute of Scientific Research of Machine-Building, the installation of one or another type of equipment may be recommended in the following conditions:

(a) Cupola—for less intricate castings when requirements for mechanical properties are not so severe, in comparatively small and medium sized foundries with short distances between cupola and molds and with direct transfer of liquid metal from cupola to ladle and then to mold, without intermediate transfer.

(b) Duplexing process—cupola and air furnaces for intricate and thin walled castings with relatively high mechanical properties in conveyor foundries. The installation of small, rotary, oil-fired furnaces may be specially recommended in such conditions as this considerably facilitates transport and reduces waste due to misrunning.

(c) Air furnaces, including Brackelsberg furnaces—in small and medium sized foundries for high duty castings when the cost of pig iron is low and that of steel scrap is high.

(d) Open hearth furnaces—in the same conditions as mentioned for air furnaces, in combined foundries for malleable iron and steel castings.

(e) Duplexing process; cupola and electric furnace—in large conveyor foundries for high duty and very intricate castings with specially high strength requirements, provided the prices for scrap are low, and iron costs are high. Basic lining may be used only in the case of high sulphur coke.

(f) Electric furnaces with cold charging—in non-conveyor foundries for very intricate castings liable to hot tears, provided the prices for electric energy, scrap, borings and turnings are very low.

Editorial Appendix

Value of the Ruble

To determine the dollar equivalent of the ruble *to the foundryman* the following comparison between the Russian and American (delivered) prices of important commodities mentioned by the authors has been prepared editorially. It is not implied that the American prices are exact averages for all foundry centers. They are taken as being typical only.

Table 19

Commodity	Price per gross ton Rubles	Dollars	Cents per Ruble
Melting Stock			
Malleable Scrap	60	17.50	29
No. 2 Pig	70	18.75	27
12% Ferro Silicon	140	27.75	20
10% Mn Spiegel	120	22.50[9]	19
Steel	60	12.00	20
Average value weighted approximately in proportion to relative amounts in mix.			
Fuel			
Foundry Coke	40	9.50	24
Foundry Coal	30	4.70	16
Foundry Coal, pulverized[10]	35	4.70	13
		Average	14
Electrical Energy			
Kw hr.	.08	.008	10

[9] No equivalent in America, estimated from 20 per cent price.

[10] It is assumed that the cost of pulverizing is approximately offset by the use of smaller sizes.

Iron, and especially pig iron and malleable scrap, are apparently relatively cheap in Russia as compared with fuel, and electrical energy is apparently quite expensive. The value of the ruble (in cents) is thus greater for fuel-fired operations than for electric melting. Coke is also a relatively cheap fuel compared with coal.

The material cost of liquid metal averaged, for all the authors' data, about one-fifth fuel and four-fifths iron. If we average the value of the ruble when buying energy as coke, coal, pulverized coal and electricity, we have a mean value of about 16 cents. Averaging this with 27 cents for iron in the ratio of 1:4 we have in round figures a value of 25 cents for the ruble which may be applied to the authors' figures to obtain an approximate translation into dollars.

Recomputing from the authors' Table 1, the value in dollars in America of the fuel or electrical energy consumed and translating the metal cost of Table 4 at 27 cents per ruble (using average values instead of maxima and minima), we obtain the values given in Table 20.

Table 20

METAL AND FUEL COST PER GROSS TON AT AMERICAN PRICES

	Air Furnace Hand-Fired	Air Furnace Pulverized Coal	Open-Hearth Furnace	Electric Furnace Basic	Electric Furnace Acid	Cupola	Brackelsberg Furnace	Electric Duplexing Acid	Electric Duplexing Basic	Air Furnace,[11] Duplexing
Fuel.....	$ 2.10	1.60	1.30	5.20	5.20	1.31	1.01	1.90	2.14	1.10
Metal.....	$19.20	19.20	19.20	17.55	16.85	19.20	18.50	19.75	19.55	20.20
Total.....	$21.30	20.80	20.50	22.75	22.05	20.51	19.51	21.65	21.69	21.30

[11] Relative consumption of coke and coal estimated as equal.

Labor and refractories do not greatly affect the production cost and effect the relative costs still less.

Valuing the ruble at 25 cents, in accordance with its purchasing power for the principal raw materials, we have a labor cost running from $1.00 to $2.00 per ton and a refractory cost from 25 cents to $1.00 per ton for the various melting methods.

No data exist for breaking down these figures into unit costs for labor or brick, and the consumption of these items per ton.

It is interesting to note that the U.S.S.R. seems to be approaching officially a 20 cent ruble.

DISCUSSION

DR. H. A. SCHWARTZ[1] (*Submitted in Written Form*): We are fortunate in having before us a paper dealing so exhaustively with so important a question as is the relative desirability of using the various types of melting furnaces available to the malleable foundryman. The fact that the data are obtained not only in a foreign country but under an entirely different industrial philosophy, makes the paper even more provocative of thought although, in some measure, it makes it more difficult to draw direct comparisons.

A few apparent misstatements, as for example, recording pearlite in specimens described as quenched from 975° C in Table 12, are probably due to difficulties of rendering Russian thoughts into English idiom and need not be too disconcerting to the American reader.

The physical properties recorded in Table 9 are all quite disappointing. Only one value of elongation and none of tensile strength there recorded would pass the A.S.T.M. specifications acceptable in the automotive trades and none would pass the railway specification. One is moved to wonder whether, if there were need for better metal, the authors would not have had to revise their ideas as to the uniformity required of the products' composition. Since they have given us no statistical support for the conclusion that any method, except perhaps the cupola, permits of satisfactory uniformity, we can not judge what their

[1] Manager of Research, National Malleable & Steel Castings Co., Cleveland, O.

standard of judgment may be. A value for the standard deviation of the composition from the desired value would here have been most informative.

It seems to this commentator that the authors have dismissed far too lightly the differences in graphitizing rate which they observed between the products of various melting units. The first stage of graphitization was complete in some metals in one-third the time required in others and the experiment in the second stage, though not carried to completion, disclosed some differences. This points to a situation in which such differences are at least not negligible.

Some of the most stimulating information in the paper is in connection with the various observations correlated with oxygen content. If the discussion rests upon a sufficiently extended basis of experiment to justify its acceptance, which is not altogether plain from the paper, then a very valuable contribution will have been made. The writer is disposed to accept, at least tentatively, the authors' viewpoint and to support it further by pointing out that the accelerators titanium, zirconium, and uranium also are readily oxidized and the proven effect of small additions may be due to such a scavenging mechanism as has interested Messrs. Girshovitch and Landa.

It has been observed by W. K. Bock in the writer's laboratory that iron melted and frozen in vacuo seems to be rendered immune to "galvanizing embrittlement". That such embrittlement was not found in the experiments reported in the paper under discussion, can not be cited in support of any particular theory that oxygen participates in the mechanism. The Russian metal was so low in phosphorus that, as shown many years ago by Bean, embrittlement was not to be expected. That such embrittlement does occur *under suitable conditions of composition*, has been so often demonstrated before and since Kikuta's work and in practice, as to leave no doubt of the existence of the phenomenon.

There seems to be a strong, and possibly an unfortunate, tendency in the paper to make a better case for basic electric melting than the data warrant. It would seem that data should not have been offered in which the authors had so little confidence that they were willing to reject them to maintain a view inconsistent with their observations. Cold basic electric melting has not commended itself economically to many of us for many years past, but duplexing in both basic and acid furnaces has been much in vogue. On the basis of such practice and of fairly extended laboratory work on commercial and experimental material, the conclusion that basic linings produce a more difficultly annealable metal seemed inescapable. The authors can not, of course, be expected to be familiar with this experimentation for it is not described in the literature except in a single patent. In the operating portion of this program, it would be difficult to maintain the suggestion that furnace operation was at fault for the furnaces were run by the same personnel. The operators had had years of experience in basic practice and less in acid. Any existing poorer results from basic practice thus should have been a reflection of the process, not of the operator.

It is not the intention, in this discussion of basic melting, to accept or reject any particular explanation for a difference of annealability

between metal made on an acid or basic bottom. The authors' explanation on the basis of oxygen and oxides may be well founded although it does not appear that *a priori* the basic process need have the higher contamination. Upon that question of fact, we should accept the result of well conducted experiment.

The oxidation losses reported in Table 4, items 1 and 2, will no doubt occasion some surprise in comparison with American practice. For example, the air furnace data account for an oxidation loss of one per cent in terms of carbon, manganese and silicon and report a total oxidation of 8 per cent of the charge, hence apparently an amount of iron equivalent to 7 per cent of the charge. The slag should then contain the surprising Fe-Mn ratio of 14 (7:0.5).

H. W. GILLETT[1] (*Submitted as Written Discussion*): This paper is phrased so that it appears to draw very general conclusions whereas its contents would only justify more limited statements. Its title should be something like "The melting of cupola-grade malleable in various types of furnaces", since the other melting media were placed under the handicap of a comparison based only upon a composition which the cupola can produce. As Dr. Schwartz has pointed out, the material studied is not a high grade malleable.

The paper does not make sufficiently clear what operating temperatures were actually used. Table 1 indicates that the various furnaces operate over a range from the low of 2550° F. in the cupola, through 2700° F. in the Brackelsberg, up to 2820° F. for the electric. The test specimens, according to paragraph 30, were all poured at 2460° F. These temperatures can be compared with those given in Joseph's paper* on pouring temperature for high grade malleable, who finds it necessary to heat to 2830° F. and never pours below 2625° F. On that basis, a furnace that can not readily produce hot metal of the proper composition would be entirely barred. So it seems strange to tabulate, as is done in Table 20, the operating costs of the various melting media as though they were on a par. One cannot properly compare directly the operating cost of a 2700 and a 2800° F. furnace.

If such a table as Table 20 is to be given at all, it should include amortization costs, which have not been brought forward from Table 5 and which, if included, would reverse the positions of the cupola and the Brackelsberg. One wonders, too, if the statement that "labor and refractories do not greatly affect relative costs" would hold if lower carbon metal and higher melting temperatures were made the basis of comparison, since it seems rather well established that in the development of the Brackelsberg type of furnace the problem of getting refractories that will allow operation at high temperature with reasonable lining life, is still an important one.

The authors draw sweeping conclusions as to oxidation of the melt and of the results due to oxidation on the basis of total oxygen figures given in Table 11, but tell nothing at all as to the method of oxygen determina-

[1] Chief Technical Advisor, Battelle Memorial Institute, Columbus, O.

* Joseph, C. F., *"Measuring and Controlling Pouring Temperatures and Fluidity,"* presented at Detroit (1936) Convention of the A.F.A. TRANSACTIONS A.F.A., vol. 44, pp. 103-132 (1936).

tion. Analysis for oxygen is far from standardized and oxygen data upon which one may rely with certainty are none too plentiful.

Moreover even a correct knowledge of total oxygen may not be very helpful, since it appears to be what the oxygen is combined with rather than its total amount that is of first importance.

As a matter of fact, the total oxygens of Table 11 are just about in the reverse order from what one would expect. A melt in the reducing atmosphere of an electric furnace would appear less likely to be high in oxygen than one agitated in the oxidizing atmosphere of the Brackelsberg.

Conclusion 9, p. 445, ascribes brittleness and white fracture to oxides and gases, and disregards the fact that as Table 13 shows some of the specimens were not annealed to complete freedom from pearlite.

The general conclusions as to quality are based on averages or maxima. No information is given as to minima and so we are left in the dark as to how the various melting media compare on the basis of freedom from specimens of very poor properties, which is too important a criterion to omit.

The paper is thought-provoking in several respects, but it is one of the dangerous type in that it badly tabulates comparative costs without sufficient emphasis upon the factors involved, which may be very different in America than in Russia, and in that it draws sweeping conclusions from observations of limited scope. The reader who runs over the last 4 pages without studying the paper in detail may be seriously misled.

E. TOUCEDA[2] (*Submitted as Written Discussion*): This paper has been read with considerable interest, because of the fact that it not only furnishes the reader with the viewpoint of those engaged in the malleable iron industry in another country, but in addition will serve as a valuable record for future reference covering furnace efficiencies and the comparative cost of metal at the spout in the case of various melting units.

While no exception can be taken to the statements that have been made in connection with these two details, the writer would point out that economy in melting is one thing, and uniformity in the composition of the hard iron from heat to heat and day to day is quite another. If one were on the point of deciding upon what melting unit to install, whether for continuous or periodic melting, would not the best procedure be to base the decision first on the ability to produce a uniform hard iron product, and then select the most efficient unit to fulfill those conditions?

In connection with some of the various details touched upon by the authors, the writer feels rather handicapped because no data have been furnished covering the dimensions of the gauge length of the test bar, especially in connection with the gauge length diameter, that is, whether it corresponds with that of the A.S.T.M. Standard test bar; whether it is rectangular or square. A knowledge of this fact is very essential in an attempt to discuss the data covered by the paper, both in respect to the bend test, and also for another reason that will now be set forth.

In Table 8 data are covered in connection with the composition of the hard iron from various melting units. In nearly all of the cases, the carbon-plus-silicon content is so very high that the writer feels certain

[2] Consultant, Malleable Founders' Society, Cleveland, O.

that not only the grip ends, but the gauge length of the bars would contain so much primary graphite as to vitiate the results of the tensile tests, provided the bar corresponds to the standard bar used in this country. Even in the case of the compositions of the bars from the basic and acid electric it would more than likely be present, and surely would be in evidence in any casting the sections of which happened to be of more than average thickness.

Considering the tensile properties in Table 9, which are so low as to confirm this opinion, we find that the average ultimate strength of 12 bars of air furnace iron is 2,500 lb. per sq. in. less than that of a similar number of bars made from cupola iron. Then again if 43,500 lb. per sq. in. is the average, some of the bars must have been considerably lower in ultimate strength. Manifestly, unless a large amount of primary graphite was present in the gauge length of these air furnace bars, it is not understandable to the writer how results this low could be produced from an air furnace heat.

In a very lengthy experience, the writer has not come across metal of this kind especially when accompanied by an elongation of 9.6 per cent, which certainly is very unusual in bars so low in ultimate strength.

It would have been interesting if the authors had supplied the analysis of the annealed bars, for that is what is needed if one is to draw conclusions based upon tensile properties, that is, it is the finished product that is tested and not the hard iron.

The authors rather stress the fact that in their opinion what determines whether or not the finished product will be good or poor is what takes place in the melting unit. The writer does not agree with this opinion and believes it is erroneous, although fully aware that normal melting conditions are essential for the securing of a good product. The writer believes better results could be obtained from poor melting conditions and a perfect heat treatment than the reverse. To emphasize the matter still further, he would explain that in 1925 an occasion arose that made him decide to carry through some tests that would demonstrate the fact that even in a normal heat, the results shown by the tensile test will be greatly influenced by the anneal. Briefly, some 300 test bars were cast consecutively from the same heat, the time of pouring being so short as to preclude the possibility of their being any material difference in composition between the bars. However, as an extra precaution when sending a set of four of these to each of 67 different companies, with the request that they be annealed in accordance with their regular practice and returned to the writer for test, they were selected haphazardly.

Briefly, the following classification was made:

Per Cent Elongation Range	No. of Plants
10—12	2
12—14	2
14—16	7
16—18	12
18—20	13
20—22	20

22—24	8
24—26	2
26—28	1

What the writer is endeavoring to make plain is the fact that in tests, such as those made by the authors for comparative purposes, it is essential that the hard iron be at least free from primary graphite and in any case that all of the bars should have been annealed at the same time and in the same oven.

It is regretted that the method used in determining the oxygen content referred to in Table 11 has not been disclosed.

The writer is in full accord with the authors in their opinion that the period for first stage graphitization is much too long in the average American practice. We seriously question the statement, however, that superheating of the liquid iron improves the quality of the product or facilitates graphitization. The authors have entered into quite a number of matters that would require too long a paper to adequately enter into in the time the writer has at his disposal. He has enjoyed reading the paper and the authors are to be congratulated for their contribution to the literature on the subject of malleable iron.

W. R. BEAN[2]: I read the paper, and I found it interesting. I do not draw any final conclusions at all from it. Perhaps the principal thing that I might say is that we, in this country, have black heart malleable not because we designed to produce black heart malleable, but because the quality and the nature or the characteristics of the materials that we have, produced black heart malleable by accident. White heart malleable was the original material here and abroad, but our sulphur was not high enough and our manganese not low enough to normally produce white heart malleable, and we therefore have black heart malleable.

I think all of the countries abroad are at a disadvantage when they undertake to try to duplicate the product which we produce in such large volume here. They have to improvise and to adjust furnace charges and run into the condition that Joseph described, from using materials that are not those that have been used as the base of our mixes.

I do not place much weight upon the cost figures recorded. It is not possible to compare results produced over there with results that we have here. There are various types of melting units. They all have their functions; they all have their place. For one result, one type of unit is the proper one to use; for another, other types are used.

It does interest me that they apparently, in a comparatively few years, have tried out all of the methods that we employ here in the production of malleable castings. I am very glad that the paper has been presented. It shows us what some of the countries that we do not know so much about are trying to do, and I feel that they deserve some credit for having produced as good results as they have in the matter of physical properties. They do not measure up anywhere near to what we have established as a standard, but perhaps they will go ahead and beat us before they are through.

AUTHORS' REPLY (*Submitted in Written Form*): We were very pleased

[2] Vice-President, Whiting Corp., Harvey, Illinois.

to read the written discussion of Dr. Schwartz, well known in the U. S. R. R. We have paid considerable attention to the criticism of such authority, and would ask Dr. Schwartz to accept our sincerest gratitude for his valuable comments.

However, we consider it necessary to elucidate certain questions raised by Dr. Schwartz, to avoid any misinterpretations by the reader.

Paragraph 39 of our paper states very clearly: "As is seen from Table 12, the system consisting of austenite and cementite gradually changes into the stable state—austenite-graphite." It is well known that the fixing of this structure cannot be brought about by quenching in water of such test bars from 975° F., as this structure is more or less subject to decomposition.

In this case, troostite, with small quantities of martensite, is usually formed, or pure troostite with sorbite, and, in very few cases (thin walled test bars, hard annealing), pure martensite. Since troostite and sorbite actually represent dispersed forms of pearlite, and since the object of Table 12 is to only show that there still is structure free cementite left, and that the stable equilibrium has been reached, we took the liberty, for the sake of better comparison with Table 13, to diverge from real structure, and to express it in normal composing elements of a normally cooled test bar.

The data of Table 9, showing rather low physical properties, should not disconcert us, as the purpose of the investigation had been, not the obtaining of high properties, but the relative estimation of the effect of the melting unit.

Therefore, low properties accidentally obtained as a result of an annoying error in the pattern, in no manner hinder the comparing of the effect of various melting units, as this error has been present in all experiments.

While comparing the uniformity of metal composition melted in different units, we considered the general discussions given in paragraphs 21 and 22 sufficient. We think that in view of the clearness of these propositions, there is no need for statistical confirmation, which may be easily given if necessary.

On the basis of our own experiments, as well as data in the literature, we consider, for instance, that with correct cupola melting, it is possible to obtain the following designations for the variations of the composition of metal:

Carbon	Silicon	Manganese	Sulphur
Per Cent	Per Cent	Per Cent	Per Cent
$\mp$ 0.15	$\mp$ 0.1	$\mp$ 0.1	$\mp$ 0.02

These variations may be reduced more than twice for other melting aggregates.

Comparative study of the data of Tables 12 and 13 does not make it possible to draw a conclusion otherwise than the one given in paragraphs 42 and 43, concerning the advantages in this respect shown by air furnaces and Brackelsberg furnaces; this has been stated by us quite definitely.

We were very pleased to hear that Dr. Schwartz accepts tentatively

our viewpoint with the various observations correlated with oxygen content, and correctly confirms it by the influence of some accelerators, such as titanium, zirconium and uranium.

This viewpoint has been expressed by us hypothetically, and its confirmation by experiment represents an important problem for further investigation.

Table 17 and paragraph 50 say that with given conditions, quenching in water at 450° C. (842° F.) does not affect in any way the brittleness of malleable iron, irrespective of previous rate of cooling from 720° C. (1328° F.).

The statement of Dr. Schwartz that the fact of formation of brittleness of malleable iron leaves no doubts, is correct, but the formation is evidently caused by a conjunction of causes.

Our experiments have shown that, with low percentage of phosphorus, brittleness is not formed in all cases, but only with melting in definite units, *i. e.*, in the presence of a definite quantity of gases and oxygen. With a higher percentage of phosphorus, brittleness evidently occurs also with lower content of gases and oxygen.

Dr. Schwartz evidently shares the opinion stated by us in paragraph 25, that basic linings produce a metal more difficult to anneal. However, such a conclusion cannot be made on the basis of our experiments. If the cause were really in the character of the lining, this should prove to have an effect both in cold and in duplexing melting. Our investigations, however, have shown that with cold melting, basic linings adversely influenced the properties of malleable iron, and the rate of graphitization, which has not been noticed when comparing acid and basic duplexing process. Therefore, we had to draw the conclusion that the results chiefly depend upon the method of carrying on the process, and not upon the character of lining.

Finally, the last comment of Dr. Schwartz. The oxidation losses reported in Table 4, items 1 and 2, is due to the inaccuracy of the text which was our fault, as we have not explained with sufficient clearness the meaning of the figures in Table 4.

With melting in the air or open hearth furnace, 20 per cent carbon loss is obtained. Therefore, carbon loss with 3 per cent carbon in the charge is $3.0 \times 0.2 = 0.6$ per cent.

A similar loss takes place in the Brackelsberg furnace. On the contrary, with melting in cupolas, the duplexing process and electric furnaces, there is a gain of carbon, owing to the carburization of the steel in the cupola, or the special carburization in the electric furnace when melting with cheap scrap. Item 2—total oxidation loss—comprises total metallurgical loss, and mechanical loss.

With melting in air furnace we have:

Loss of Carbon	$3.0 \times 0.2 = 0.6$
Loss of Silicon	$1.5 \times 0.3 = 0.45$
Loss of Manganese	$0.5 \times 0.5 = 0.25$
Loss of Ferrum	$= 1.20$
Total loss	2.50

Therefore, the mechanical losses are: $8.0 - 2.5 = 5.5$ per cent.

Consequently the determination of ferro-manganese ratio proposed by Dr. Schwartz should be recalculated with values corrected as above.

In conclusion, we would consider it necessary to mention that the problem set forth in the work is of such a scale that its solution given by us may naturally be considered as a first step towards its solution. It is to be hoped that further work would throw more light on these complicated and important questions.

The interest in this question shown by the American Foundrymen's Association shows the true importance of the theme both for theory and for practice, and we take this opportunity to express our deep gratitude for the appreciation and interest shown by American foundrymen, and in particular by Dr. H. A. Schwartz, to whom we are sending our sincerest thanks for his valuable comments and his written discussion.

Manganese Bronze—A Correlated Abstract

By F. R. Hensel,* Indianapolis, Ind.

Abstract

This correlated abstract on manganese bronze presents a condensed review of the principal factors in the production of castings. The outline followed in the main is that used by the Nonferrous Division Committee on Recommended Practices. The items covered are chemical composition, melting procedure, control of composition, furnaces, removal of impurities in scrap, casting of ingots and chill castings, temperature measurements, sand casting, gating, feeding, pouring, zinc equivalent, effect of hardening elements on brass, physical properties, microstructure, effects of impurities, fields of application, effect of temperature, embrittlement and heat treatment. An extensive bibliography is appended.

Introduction

1. Manganese bronze is really a brass to which have been added small amounts of aluminum, iron, manganese, nickel and tin for strengthening the well known brass containing 60 per cent copper and 40 per cent zinc. It has been known since about 1876 (British Patent 482). The alloy has been created mainly by the demand for a non-ferrous metal which, as compared with the same weight of mild steel, has a high corrosion resistance and the same tensile strength. Some of the most outstanding researches on manganese bronze were done by Guillet, Smalley and Ellis.

Chemical Composition

2. The chemical composition of manganese bronze varies according to the physical properties required. Specifications for

* P. R. Mallory & Co., Inc.

Note: This paper was presented at a session on Non-Ferrous Casting Practice at the 1936 Convention of A.F.A. in Detroit, Mich.

manganese bronze conform generally to the following composition ranges*:

	Per Cent
Copper	55 to 60
Tin	0 to 1.5
Lead	0 to 1.4
Zinc	38 to 42
Iron	0 to 2
Aluminum	0 to 1.5
Manganese	0 to 3.5

3. There are a large number of commercial alloys with different trade names and slightly modified compositions. In some cases, small percentages of titanium-copper are added.

MELTING PROCEDURE

4. It can be stated that possibly 50 per cent of the troubles that bronze castings are heir to are due at some stage to faulty melting conditions. It should be realized that it is much more important to melt correctly than to attempt to correct the errors due to bad melting by deoxidants and nostrums afterward.

5. The alloy can be prepared by using pure copper, and special hardeners or the pure elements or manganese bronze in ingot form might be used for remelting. These ingots are usually cast in forms having a notched flat bottom. They are approximately 3 x 2¾ in. wide, 12 in. long properly tapered to slip easily from the iron mold. The requirements, as to chemical composition of these ingots, are the same as those outlined above. The principal features to be observed in melting are:

(a) Preparation of suitable stock alloys for the introduction of the more refractory metals.

(b) Correct selection of materials, calculating the mixture from the actual composition and allowing for melting losses.

(c) Carefully weighing out the necessary additions and charging in their correct order.

(d) Avoid the use of scrap of doubtful chemical composition particularly with regard to iron, aluminum, tin, silicon and dross contamination.

(e) Melt as rapidly as possible in a neutral atmosphere, but never superheat more than 20 per cent of the actual

* *"Cast Metals Handbook,"* American Foundryman's Association, (1935) p. 363.

melting temperature and control pyrometrically. It is suggested in crucible melting that the crucible be well preheated. It has been found in many cases that a reducing atmosphere contributes largely to heavy gas absorption in the molten metal and the general trend of opinion is that a slightly oxidized atmosphere is to be preferred in view of this danger. The charge should, to counteract the effects of this slightly oxidizing atmosphere, be kept covered with charcoal. The use of charcoal will not produce gassing if properly applied. In no case should charcoal be placed in the bottom of a preheated ladle and hot metal poured on top of it.

(f) Avoid retension in the furnace for long periods after correct remelting. Where this is impossible, carefully control the temperature. Cover with a protecting slag and adjust for zinc losses.

(g) Mix well but do not oxidize in doing so.

(h) Deoxidize with small amount of phosphor-copper or phosphor-tin just before casting. In the case that no manganese is contained in the alloy, use copper-manganese both as a deoxidizer and as a desulphurizer. Deoxidation of brass, as usually thought of, is unnecessary. With the amount of zinc that is present, it appears impossible to have copper oxide present. For the most part, these deoxidizers are what might be termed fluidizers.

(i) Avoid contamination with slag in the ladle.

CONTROL OF COMPOSITION

6. The rapid change in properties accompanying the variation of the proportions of the alpha and beta constituents in manganese bronze, necessitates careful control of composition. The best practice in founding manganese bronze is to use previously made ingot metal, and if this is done, there is no appreciable change in the contents of the additional metals such as iron, manganese, tin, etc. on remelting. Attention need only be concentrated on the zinc content. In crucible melting under reasonable control, the loss of zinc is generally sufficiently uniform and consistent to permit a suitable allowance for this to be made in the original manufacture of the ingot. A high purity zinc should be used, otherwise an excess of lead may be introduced into the alloy. In

this connection, it has been stated that a higher lead content can be offset by a higher aluminum content. In air furnace melting, such as is used for castings weighing some tons, the loss of zinc is less predictable. Fortunately, rapid means of estimating the zinc content in most manganese bronzes is possible by the examination of the fracture or the angle of bend of sample chilled bars. Using this method, an experienced operator can judge when the correct composition is obtained to an accuracy of plus or minus 5 per cent.

7. By using the elements for the manufacture of manganese bronze pigs, it is recommended first to place a layer of charcoal at the bottom of the crucible, then the ferromanganese in the form of small chips. The iron in small divisions is next added and the crucible filled up with the copper. The charge is covered with charcoal and melted as quickly as possible. When molten, the aluminum is added, and finally the zinc. The metal is thoroughly stirred, skimmed and poured into ingot molds for remelting.

8. The addition of the alloying ingredients can also be made by means of special alloys containing high percentages of iron, manganese, aluminum and tin. These can be purchased as "Manganese Bronze Hardeners" and instructions are usually furnished by the supplier as to percentages to be added to obtain certain physical properties. Manganese can be added as cupro-manganese containing about 30 per cent manganese. Due to its low melting point of 1580 to 1600° F. (860-870° C.) it is easily dissolved. Ferromanganese can be used to get iron into the melt. Ferromanganese dissolves quite readily in copper because of the great affinity of manganese for copper.

FURNACES

A. Crucible Melting

9. Despite the high cost of fuel and of crucibles, this is still the most commonly used method and is favored because of the flexibility of temperature control, the ease of mixing, low melting losses and protection from dirt and obnoxious gasses during melting.

B. Open Hearth Furnaces

10. The common objection to open hearth furnaces in the melting of brasses is the large surface of metal exposed to the furnace gases which, if sulphurous in nature, are injurious. Carbon monoxide, sulphur-dioxide, nitrogen, hydrogen and various hydro-

carbon gasses, are present in all brasses, sound and unsound. If during melting the charge is overheated or directly contaminated with these fumes, they are absorbed in excessive quantities and their evolution on cooling is the principal cause of blow holes in castings. A few logs of hard wood charged during the melting down period, an occasional shovel full of *hard wood* charcoal or anthracite coal and a suitable protecting flux, are recommended. The choice of the flux is extensive, but either of the following are recommended by Smalley:

(1) Equal parts by weight of plaster of Paris (calcium sulphate) and fluorspar (calcium fluoxide).

(2) 30 per cent soda ash, 20 per cent fine silica sand, 33 per cent fluorspar and 17 per cent borax.

11. These fluxes should be ground. Two to 3 per cent by weight of charge is a sufficiently large addition. It might be well to recall that fluxes in metal melting can be used for a variety of reasons:

(1) As a protection, forming a liquid covering on the surface of the metal.

(2) As a reducing agent. Such fluxes generally contain such elements as carbon or manganese.

(3) As a melting agent, acting by dissolving the inclusions and oxides of the molten metals (such as borax).

(4) As an agitator, by evolution of gasses and vapors, stirring up the metals.

12. For most fluxes, the action is complex and multiple. Melting should not be forced. For large castings, several furnaces may be used and the metal mixed in a preheated ladle.

C. Electric Furnaces

13. The induction furnace is ideal. Zinc losses and impurity contamination are reduced to minimum and the melting temperature can be kept under perfect control. The indirect arc rocking furnace has given very satisfactory results.

D. Cupola

14. Manganese bronze has also been made in the cupola for casting large propellers, and it is claimed that 60,000 lb. per sq. in. tensile strength, with from 18 to 22 per cent elongation, can be obtained.

SCRAP RECOVERY

15. Where the chemical composition is uncertain, and when the metal is either of undecidable form or dirty, it should be run down into pig form. If briquetting is possible, 2 to 3 per cent of borax or plaster of Paris should be mixed in and sprinkled with water immediately before pressing. If this procedure is not possible the swarf should be mixed with 3 to 5 per cent plaster of Paris or 5 per cent of No. 2 flux mixture given above, together with a little coal dust and melting with a reduced flame.

16. The objection to the use of open hearth furnaces lined with ganister is the accumulation of slag which banks up the hearth and puts the furnace out of commission. To avoid this, the bottom should be flowed with a suitable flux such as plaster of Paris with or without soda ash and fluorspar according to the nature of the slag.

17. With correctly refined scrap of desired composition, up to 60 per cent may be used with safety. Of the ordinary domestic scrap such as jets, risers and clean overflow metal, no more than 30 per cent is recommended. All scrap should be tested carefully for silicon, arsenic, tin and antimony.

18. To recover foundry skimmings, zinc dross, brass trimmings, aluminum turnings and other foundry scrap, the use of the reverbatory furnace is suggested. The idea is to compound the various materials available so as to cause one to react with the other to the mutual benefit of all the ingredients going into the charge. Charcoal and common salt are usually added to the charges on account of their reducing and fluxing properties. Contact, while in a molten or semi-molten state, of metallic copper and partly oxidized zinc in the presence of charcoal, develops a condition extremely conducive to a thorough deoxidation and alloying of all the metallic ingredients. The metal produced is sound and homogeneous, and capable of being cast in ordinary foundry practice in the same manner as the so-called high grades of manganese bronze.

REMOVAL OF IMPURITIES IN SCRAP

A. Iron

19. Iron, existing as a constituent of lower density than brass, rises to the surface in melting. By using a silicious slag in an oxidizing atmosphere, much of the iron may be oxidized out into the slag as a ferrous silicate.

B. Sulphur

20. Some protection against sulphur is afforded by the introduction of a small amount of sodium fluoride into the melt. This should be worked in from the bottom, followed by a little cupromanganese. This procedure is a safeguard against gassing and porosity both of which are common defects of castings made from scrap.

Casting of Ingots and Chill Castings

21. Ingot and chill molds should be preheated to a temperature of 100 to 200° F. (40 to 90° C.), cleaned and dressed with an organic material. When a clean, smooth skin is desired, a simple tallow of heavy mineral oil dressing is recommended. For general work, a facing of tar followed by a second one consisting of a mixture of cylinder oil of over 480° F. (250° C.) flash point mixed with powdered charcoal and followed by a dusting of fine charcoal may be used. Polishing-in of black lead or smoking with burning resin or creosote oil is quite satisfactory for ingots.

22. A 10 per cent superheat is a satisfactory casting temperature although for heavy ingots it may be reduced to 7 per cent. Top pouring through a runner basin is recommended. For the manufacture of high class stampings or sheet, the ingot or slab should be scalped.

Temperature Measurement

23. Manganese bronze gives off more or less fumes in the ladle and for this reason optical and radiation methods of pyrometry are usually of little value. Temperature measurements may, however, be obtained with adequate accuracy with an immersion thermocouple. Pyrometers of this type are commercially available from a number of sources.

Sand Casting

24. The selection of the correct molding materials is very important in the manufacture of brass castings. The molding of large castings such as propellers follows the usual practice observed in brick and loam molding. The entire mold is dried in a drying oven. A container is fixed over the runner which is kept filled with hot metal during pouring. In large castings a 2 to 3 in. diameter runner may be used in conjunction with a splash gate and a slightly tangential entry at the lowest part of the casting.

The properties of a molding sand which should be controlled are the following:

(a) Bond, *i. e.*, Strength
(b) Grain Size or Texture
(c) Heat Conductivity
(d) Refractoriness
(e) Permeability and Longevity

25. Conditions covering the general principles of molding are very similar to those of ordinary brass castings.

26. Unsoundness is often the result of the use of unsuitable sand. It may contain too much moisture and have a low permeability. Excessive moisture gives rise to the formation of steam which can react with oxides in the molten metal, resulting in an undue amount of hydrogen, which is taken up by the metal when molten and later released as it cools down.

27. The permeability, of course, affects to a considerable extent the passage of gasses through the mold and it is well worth while to periodically carry out permeability tests. It is further important to check periodically the moisture of the sand.

GATING

28. The designer and foundryman should work hand in hand. Every manganese bronze casting should be designed with reference to a given position in the flask. The position being determined, the various portions of the casting should be so arranged that they are connected by a rising channel of increasing cross section and with a minimum of offsets with one of the risers, which of course, should be of much greater diameter than the thickest part of the casting.

29. The molds should be filled so that the stream of metal is continuous, and not broken up on entering the mold. Any agitation of the metal in passing through the mold creates a scum or dross that may cause a defect in the casting. To eliminate the possibility of such a condition, the use of horn gates are adopted whenever possible. Strainer cores and skim or choke gates are sometimes used on manganese bronze castings.

30. Whenever possible, castings should be poured from the bottom. This is particularly important in brasses containing aluminum and manganese which must be cast under the exclusion of air as far as possible. For flat, circular castings, whirl gates are

preferable. For cylinders and the like, the metal should be run from the bottom by means of a series of tangentially cut "V"-shaped jets. A straight run of the metal should be arranged and it should be avoided that the metal stream will directly wash delicate cores or projections in the mold. Also, sharp angles at turning points should be avoided. Castings should generally be run in the thinnest sections. This gives the thinnest sections the benefit of the hottest metal.

FEEDING

31. In general, the foundry technique for manganese bronze resembles that for aluminum bronzes but the difficulties are definitely not so great as in the latter case.

32. Proper feeding is important to avoid unsoundness due to shrinkage. In large castings, such as marine propellers weighing 8 to 10 tons, the feeding heads should remain in a liquid state for as long as 2 hours after pouring. Shrinkage can be differentiated into these varieties:

(a) Liquid shrinkage
(b) Solidification shrinkage
(c) Solid shrinkage

33. The most critical period during the production of sound castings is the solidification period, that is, the transition from liquid to solid. Molding should be done in such a way that the heavy sections are placed in the upper part of the mold. The heavy sections which are shut off from the lighter sections should be connected to a good feeding riser by a section of increasing dimensions. To equalize the rate of cooling, chills should be used on the thicker sections. The risers should be appreciably larger at the top than the thickest section of the casting. They should be placed at the highest point of the casting and directly above the thickest sections. It is false economy to cut down the number or size of the risers. They should be filled with hot metal, preferably from another ladle or crucible. Small dummy risers should be placed where dirt is likely to be trapped. Where rod feeding is necessary, the right section of rod should be chosen and the rod should be preheated before immersing.

POURING

34. The first and foremost factor in controlling the production of sound castings is the selection of the correct casting tem-

peratures from the dimensions and requirements of the job. Never cast with less than 6 per cent super heat or over 15 per cent.

35. The casting temperature of the manganese bronze alloys usually ranges between 1700 to 1900° F. (930 to 1030° C.), according to the chemical composition. For an alloy with a melting point of 1650° F. (900° C.), an optimum casting temperature of 1725 to 1760° F. (940 to 960° C.) for large propellers, or 1690 to 1705° F. (920 to 930° C.) for ingots or forgings is recommended.

36. The smallest grain size, the greatest hardness and, with limitations, the highest density, all result from the most rapid rate of solidification. Other things being equal, the lowest casting temperature should give the most rapid rate of solidification. From a practical standpoint, it is not always possible however, to work at the most rapid rate of solidification with sand molds. The actual casting temperature is best found from the copper-zinc constitutional diagram adding the desired percentage of super-heat to the melting point figure. For actual foundry use, small quantities of special metals (under 0.5 per cent) need not be taken into account. Exceeding this amount they should be calculated back into either their copper or zinc equivalents. When the alloy is complex, an actual freezing temperature determination is the only satisfactory method.

Defects Due to Too Cold or Too Hot Pouring

37. If manganese bronze is cast *too cold,* the following defects are encountered:

(a) Short Runs.
(b) No Strength.
(c) Brittleness.
(d) Drawing.
(e) Blow Holes.
(f) Cracks.
(g) Contamination with Oxides.

38. If the material is cast *too hot,* the following defects are usually found:

(a) Weak Crystal Zones.
(b) Segregation.
(c) Poor Physical Properties.
(d) Incorrect Composition.
(e) Honeycombing.

The temperature should be measured before casting.

STRIPPING THE CASTING

39. The grain size is materially influenced by the rate of cooling. Hence, the uncovering of certain portions of the casting plays an important part in preventing casting stresses and abnormal grain growth. In the case of large castings, some days are allowed to elapse before the casting is completely uncovered and lifted from the bed of the mold.

ZINC EQUIVALENT

40. Two principal factors govern the mechanical properties of cast manganese bronzes. These are microstructure and chemical composition. The most useful bronzes are those having an alpha beta or a beta structure. Leon Guillet suggested* an ingenious scheme for converting ternary alloys to equivalent copper-zinc binary alloys. He found that third elements, when added in small amounts, go into solid solution and have the same effect on the microstructure as the addition of more zinc. Guertler** is doubtful about the value of the zinc equivalence factors. Guillet's list of "zinc equivalence" factors is shown in Table 1.

Table 1

ZINC EQUIVALENCE FACTORS.

Metal	Zinc Equivalent
Aluminum	6.0
Tin	2.0
Iron	0.9
Manganese	0.5
(Nickel)	(1.1 parts copper)

41. This list ascribes certain numerical values to each of the added metals to denote their quantitative effect in terms of equivalent proportions of zinc on the relative volumes of alpha and beta phases in a manganese bronze. The percentage of each metal such as aluminum, manganese, iron and tin is multiplied by the coefficient of equivalence. These results are added to the actual zinc percentage. The apparent zinc percentage divided by the sum of the apparent zinc percentage and the actual copper percentage gives the zinc equivalent of the alloy. In practice, these

* REV DE METALLURGIE (1905) No. 2, p. 97; (1906) No. 3, p. 243; (1920) No. 17, p. 561.

** ZTSCHR. F. METALLKUNDE, 1921, No. 13, p. 128.

factors are found to operate with good accuracy so long as the particular element considered is not present in amounts greater than 2 per cent.

42. The transition from the all alpha structure to the all beta takes place in the sand-cast, plain copper-zinc alloys over the range of zinc contents from 34 to 45 per cent.

43. Table 2 shows the progressive change in the mechanical properties over this range of composition in sand cast test bars of the straight copper-zinc alloys. It is of interest to compare these results with those of a manganese bronze, shown in Table 3, con-

Table 2

MECHANICAL PROPERTIES OF SIMPLE BRASSES.

Sand Cast

Zinc Percent	Alpha Phase Percent	Maximum Stress lbs. per sq. in.	Elongation Percent in 2 in.	Brinell Hardness
33.7	100	33,600	63	55
35.0	88	42,800	59	59
38.0	75	47,152	56	64
40.1	69	51,520	55	72
41.8	55	55,104	50	80
43.7	14	62,272	27	102
45.5	0	68,096	27	105

Table 3

MECHANICAL PROPERTIES OF MANGANESE BRONZE

Sand Cast

Zinc Percent	Alpha Phase Percent	Maximum Stress lbs. per sq. in.	Elongation Percent in 2 in.	Brinell Hardness
31.0	100	46,592	24	72
32.9	78	53,312	36	75
37.5	70	60,928	50	85
39.2	45	69,216	42	95
41.1	25	76,608	28	121
44.1	0	83,328	21	129
47.8	0*	54,656	4	138

* Delta present.

taining besides copper and zinc, 1 per cent iron, 1 per cent tin, 0.25 per cent aluminum, and 0.25 per cent manganese.

44. Just as in the plain copper-zinc alloys, the increase of zinc content in manganese bronze diminishes the proportion of the alpha constituent causing a progressive increase in hardness and also in tensile strength, until a wholly beta microstructure is attained. It is seen, that in the particular manganese bronze considered, absence of the beta constituent does not correspond to the maximum ductility. Since the mechanical properties are a function of the structure, it is possible to control the structure rather than the actual zinc content. Various elements can be used for this purpose, according to their zinc equivalent.

EFFECT OF HARDENING ELEMENTS ON BRASS

45. Iron refines the grain and improves the forging qualities. Beside refining the grain, the iron also seems to produce a more even grain size and uniformity of the shape and size of the alpha constituent. The explanation of the mechanism of its action is that iron exists in brass as an insoluble constituent rich in iron in the form of finely divided particles, each of which tends to act as a nucleus. Grain refining is obtained with less than 0.35 per cent iron.

46. Aluminum strengthens, but causes coarse crystallization and increased shrinkage so that the additional hardness is possibly more safely obtained by the use of tin.

47. The tin must be kept low for forgings, otherwise the alloy will crack. The solubility of tin depends upon the zinc content. The lower the zinc the more tin can go into solution. In complex brasses of high ductility, 0.7 per cent is the maximum amount that should be used. In naval brass, the limit is 1 per cent. The presence of tin in manganese bronze seems also to be desirable for its influence in retarding corrosion.

48. Manganese improves the elastic limit, but reduces the resistance to shock if present in any appreciable quantity. If only a moderate amount of manganese is present, it will act primarily as a deoxidizing agent. When introduced in quantities in excess of that necessity to deoxidize, its ready oxidation may become responsible for considerable trouble in casting and special precautions are necessary in temperature control and method of pouring or ex-foliation of oxide will be encountered and cause defective work.

49. Considering the accumulated facts regarding the strength relationships in manganese bronze, Corson comes to the conclusion* that formation of a compound such as Mn Al or Mn_2 Sn dispersed in the beta phase must be responsible for the high strength of manganese bronze in the absence of iron and nickel.

50. It was pointed out by Livermore that the object of the manganese is not so much to act as an ingredient of the alloy as to serve as a carrier of the iron necessary to insure the required strength and elastic limit. O. W. Ellis** thinks that the use of metals other than aluminum, iron and manganese in complex brasses is unwarranted. He considers complex brasses to be essentially aluminum brasses to which small proportions of iron and manganese are added. The former to increase the ductility without reducing the strength and the latter for increasing the strength without reducing the ductility.

51. Within the permissible limits, lead facilitates machining. Lead is stated to be soluble to the extent of 0.9 per cent in plain brass. In manganese bronze, generally not more than 0.2 to 0.3 per cent is desirable. It is stated by Ellis the effect of lead on sand cast manganese bronze was much less marked than in rolled manganese bronze. Where in rolled material the tensile strength and ductility fell sharply with even small additions, it appears that in sand castings as much as 0.5 per cent lead had little appreciable effect on the tensile strength.

PHYSICAL PROPERTIES (SAND CAST)

52. The tensile properties may be determined on "cast to size" test bars. A "feeder" is connected to the entire length of the test bar. It is important that the opening from test bar to "feeder" be made to thicken sharply towards the "feeder". The "feeder" should be about 3 times as heavy as the test bar. The bar being so much smaller than the "feeder", solidifies first, and when this is taking place metal is continually being drawn by gravity from the molten reservoir in the "feeder." This insures clean and sound test bars.

53. In Table 4 are listed minimum and average physical test requirements.

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* Corson, M. G., *"Manganese in Non-Ferrous Alloys,"* PROC. Inst. of Metals Div., A.I.M.E. (1928), p. 495.

** IRON AGE, Mar. 14 (1929), pp. 740-741.

Table 4

AVERAGE PHYSICAL REQUIREMENTS

	Minimum	Average
Ultimate Strength, lb. per. sq. in.	55,000	65,000 to 90,000
Yield Point, lb. per. sq. in.	20,000	30,000 to 50,000
Elongation, per cent	25	35 to 15
Compression Elastic Limit, lb. per sq. in.		28,000
Reduction of Area, per cent	25	
Brinell hardness	90	100 to 180
Melting range	1674 to 1697° F. 912 to 925° C.	
Specific gravity	8.36	
Weight, per cu. in.	0.302	
Coefficient of expansion, 0 to 100° C.	0.0000206	
Shrinkage in 12 in., in.	0.187	
Per Cent Conductivity, (Copper equals 100)	22	

MICROSTRUCTURE

54. The manganese brass ranges from an all beta structure to approximately a 70 per cent alpha and approximately a 30 per cent beta structure. Throughout all, will be distributed tiny crystals that are known as the blue etching constituent. The presence and amount of this constituent depend on the extent of iron content of the alloy and to a smaller extent on the aluminum content. The presence or absence of manganese has, apparently, no influence on its formation. The addition of aluminum or manganese up to 4 per cent has no effect on the proportion of the constituent present, but an addition of more than 4 per cent of iron considerably reduces its amount. Although the blue constituent is very hard, it does not seem to give any trouble in machining, on account of the even distribution.

55. The relative amount and also the shape of alpha has an important influence on the physical properties. The principal controlling factor on the microstructure apart from the composition is the rate of cooling. Iron appears to promote greater uniformity of size and shape of the alpha and beta crystals in a brass of duplex structure, as stated above.

EFFECTS OF IMPURITIES

56. In special brasses the effect of impurities is usually more marked than in simple brasses. Silicon and magnesium even in

small percentages make the alloys brittle. An excess amount of phosphorus (over 0.15 per cent), causes them to be porous. Arsenic, cadmium, antimony and bismuth are among the most dangerous impurities in brass, but while small quantities of these might be harmful singly, they may not be objectionable if in combination with each other or with some other particular element.

FIELD OF APPLICATIONS

57. The applications of alpha beta manganese bronze castings are very numerous. One of the best known examples is that of marine propellers, the casting weight of which may vary from 40 lb. to 120,000 lb. Alpha beta manganese bronzes are suitable for parts which are highly stressed and exposed to sea water. At the same time, care should be taken in marine applications to guard against abnormally corrosive conditions, such as are developed by galvanic action due to the proximity of large masses of copper, as in copper sheathed hulls.

58. For land uses the manganese bronzes find application on account of their strength, resistance to corrosion and non-magnetic properties. Examples are gun mountings, races, rotor and caps, rings in turbo-electric generators.

59. Beta manganese bronzes give satisfactory service in applications where non-magnetic properties and a capacity to withstand high centrifugal stresses are required.

60. Caution is necessary in using *beta* manganese bronzes for castings which may be exposed to corrosive conditions, and when the beta bronze contains aluminum, it should not be adopted for parts subjected to stress while in contact with sea water, saline ammonical or acid solutions. Under these conditions, the aluminum bearing beta manganese bronzes are liable to intercrystalline cracking.

61. It is possible to use manganese bronze for resurfacing such parts as Diesel engine pistons, distributing valves of petrol pumps, etc., by means of the gas torch.

EFFECT OF TEMPERATURE

62. At temperatures above 1300° F. (700° C.) there occurs a very rapid crystal growth.

63. All beta brasses suffer from a long period of heat fragility regardless of their chemical composition. Ordinary beta brasses

of the copper zinc series have a period of hot shortness extending from 600 to 850°F. (315 to 455°C.). By adding aluminum this range is increased from 440 to 1035°F. (226 to 558°C.).

64. Beta alloys may be worked at temperatures above 1290°F. (700°C.), but there is great danger in doing so, owing to the abnormally rapid crystal growth at such temperatures, which is not readily eliminated by a continuance of work at lower temperatures. In other words, beta manganese bronzes are brittle alloys, and slight overheating might render them unsafe in use.

65. The tensile strength of manganese bronze is about 40 per cent greater at —148°F. (—100°C.) than at +68°F. (+20°C.), the elongation is also increased. While aluminum bronze shows a marked improvement in ductility at —40°F. (—40°C.) but again becomes less ductile at lower temperatures, manganese bronze shows an improvement in ductility throughout the range.

EMBRITTLEMENT

67. Manganese bronze fails rapidly under slight stress, as a result of intercrystalline penetration when in contact with fluid metals, such as mercury, molten tin, lead.

HEAT TREATMENT

68. Manganese bronzes can be improved by heat treatment. Alpha and beta brasses are unaffected by the rate of cooling; only the alpha-beta brasses are amenable to heat treatment. In the latter case, the material must be quenched from the homogeneous beta region. In tempering, this beta constituent is decomposed, the alpha being precipitated out of solution and at 1112°F. (600°C.) the normal structure is restored again.

69. While the heat treatment of alpha-beta brasses may be exploited advantageously, more harm than good might result if not scientifically performed, for unless the alpha constituent is completely absorbed on heating and the quenching sufficiently drastic, both the strength and ductility are impaired rather than improved.

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(*Discussion begins on Page 492*)

Production of Aluminum Bronze Castings to Withstand High Pressure

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Abstract

Although many papers have been published which deal with the physical properties of aluminum bronze and its composition, heat treatment and relation of various compositions to each other, few have dealt with the practical side of the problem which is of paramount interest to foundrymen. This paper describes in detail the foundry practice used in the production of seven types of aluminum bronze castings weighing between 3 and 150 lb. After outlining briefly the metal used, the author describes melting practice and pouring temperatures for the various type castings and follows with detailed information on the molding practice, including molding and core sand mixtures, gating methods, risering and the use of chills.

1. A number of excellent articles and papers have been published in this country and abroad concerning aluminum bronzes. In general, those papers have dealt with chemical compositions, physical properties, heat treatments, etc., and have been valuable to the engineer, chemist and metallurgist but have been of much less value to foundrymen than would be a detailed description of the operations involved in the production of aluminum bronze castings. After all, the foundryman is the man who must materialize the specifications set forth by the engineer and therefore information about practical experiences with gating methods, methods of molding, risering, etc., should be of mutual interest.

2. Many parts of the products manufactured by the company with which the author is associated, are made of aluminum bronze and the non-ferrous foundry department is entrusted with the successful and economical production of these requirements. This department has, over a period of years, made many observations and conducted many tests and finally has arrived at what it considers to be good practice in the production of aluminum bronze castings of the type required by the company. Details of the practices used are outlined in the following paper.

* Superintendent, Brass Foundry, Goulds Pumps, Inc.

Note: This paper was presented at a session of Non-Ferrous Casting Practice at the 1936 Convention of A.F.A. in Detroit, Mich.

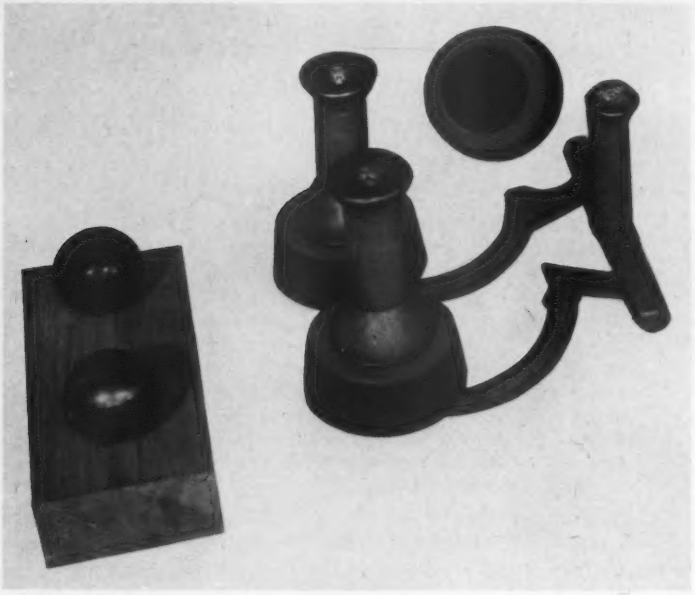

FIG. 1—SOLID BALL, 3¼-IN. DIAMETER, SHOWING GATING ARRANGEMENT AND CHILLS. NOTE DROSS IN COPE RUNNER.

3. In the manufacture of the type of castings which will be discussed, aluminum bronze ingots of uniform analysis (87 per cent copper, 10.50 per cent aluminum, 2.50 per cent iron) are purchased from a reputable metal dealer. For complicated parts, about two-thirds new metal and the remainder gates and risers is used. For simple parts, such as glands and covers, the proportion is reversed to avoid accumulation of gates, risers and scrap.

4. It was not found economical to use chips or borings returned to the foundry from the machine shop and arrangements were made with the ingot supply house to take them back. Thirty tons of aluminum bronze castings left between 1½ and 2 tons of chips. When an attempt was made to use the chips, the loss of castings, caused by the dross that was formed by these chips, was greater than the saving in metal.

5. It is good practice to cover the molten metal with charcoal but, by all means, avoid placing it in the bottom of the crucible before charging. It was found that charcoal placed at the bottom of the pot generated gases which were freely absorbed by the

molten metal. After the metal was poured, these gases were liberated during solidification with the result that all castings poured from this heat were porous. How badly the metal was gassed can be seen by the large swelling of the risers in Fig. 7.

6. The pouring temperature should be the lowest at which a complete casting of any one design may be obtained with regularity. The large cylinders (Fig. 7) are poured at 2050° F. Heavy covers are poured at 1950° F. and ball valves (Figs. 1 and 2), in consideration of the heavy cast iron chills cooling the metal rapidly, are poured at 2150° F.

7. A much wider pouring range than that allowed for phosphor-bronze or 88-10-2 for instance, is permissible without causing a serious reduction in physical properties. The lower temperature is always to be preferred where feasible, because the lower the temperature, the lower the total shrinkage. Pouring temperatures can be lowered for a certain casting by pouring it two up instead of pouring the metal through a single sprue.

8. Pouring must be accomplished with the least possible amount of turbulence. Molten aluminum bronze is covered with

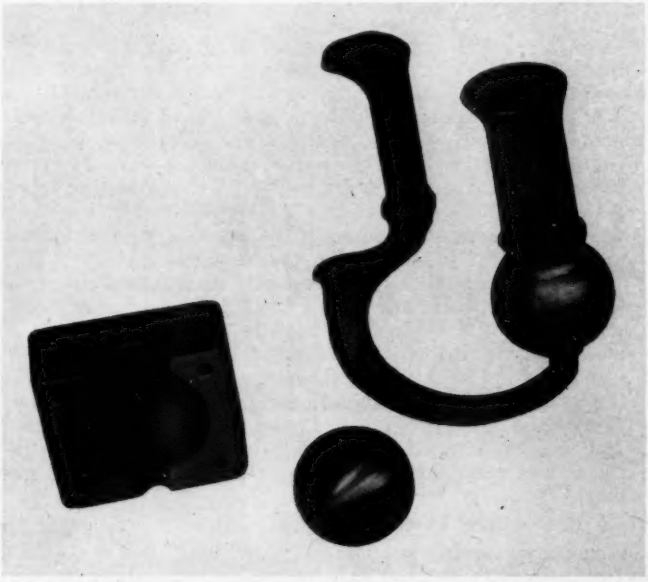

FIG. 2—SOLID BALL, 4¼-IN. DIAMETER, SHOWING ONE-HALF CHILL AND GATING ARRANGEMENT WITH CASTING ATTACHED.

a fine film of oxide and when this film is skimmed off, another film is formed immediately. This fine, though tough, film caused by interruption in the even flow of metal will prevent union with the main body of metal. Such shots, films or folds, or whatever you may call them, become incorporated in the casting without being fused into it and frequently cause the casting to leak under pressure.

GATING

9. The importance of proper gating and pouring is aptly brought out in an article by the late Charles Vickers,[1] two paragraphs of which are quoted herewith:

> "If the sand is of the proper 'temper' and the mold of the right density, the metal will lie quietly on the sand surfaces after it had been introduced to the mold and no lather will form on the metal in the mold, and, provided none has been formed during the pouring, the casting cannot be otherwise than perfect. To get the metal into the mold without lathering is the problem. The best way of gating it is at the bottom, as this will allow the molten metal to rise gently in the mold. While it is important to introduce the metal at the lowest point of the casting, it is equally important to do this in a manner that will avoid the formation of ripples, as each ripple produces a little foam. Thus if the bronze is introduced to the mold through a "horn gate," dross will be formed at the point of entry and will take the form of a ring, due to the fact of the metal spouting up through the horn gate and falling back, produces a fringe of lather which remains as a part of the casting. The horn gate acts like a fountain, because it is generally made tapering in contour, increasing in diameter as it recedes from the casting; the effect being that of a nozzle. To avoid this, it is necessary when using horn gates to make the latter of greatest diameter at the point of juncture with the casting.
>
> "This foam or lather is nothing more than air enclosed by metallic film. It is a mass of bubbles the same as foam on soapy water. With it, there may be a little dross entangled, and the mass rises on the surface of the bronze and lodges on the upper surfaces of the casting, where it is compressed by the pressure of the metal behind, producing the well known drossy spots found on castings of aluminum bronze all too frequently. The same effect is produced in lesser degree in the case of manganese bronze and all metals containing aluminum."

10. An article[2] by Carpenter and Edwards is also quite pertinent and a paragraph is quoted herewith:

[1] Vickers, Charles, *"The Founding of Aluminum Bronze,"* BRASS WORLD, August, 1920.

[2] Carpenter, H. C. H. and Edwards, C. A., *"Hydraulic Pressure Tests of Aluminum Bronze Castings,"* ENGINEERING NEWS, vol. 65, no. 13, 1911.

"By using a large riser on the lug, it was possible to see the metal enter and gradually fill the mold. The metal entering the mold through the well at the bottom of the gate was quite clean. On this metal, a skin of alumina formed at once. If, as in the authors' earlier experiments, the metal enters quickly, ripples or waves are formed which break through this skin and expose fresh surfaces of clean metal, which are immediately oxidized. The perpetual recurrence of this process causes the formation of a large amount of dross. This is not carried out of the mold through the riser. The moment it comes in contact with the sides of the mold it sticks. This is why it is present in the castings, and particularly in the upper part. Thus any factor which produces ripples or any other kind of agitation of the metal, causes a much larger surface to be exposed, and so more alumina is formed. This skin of alumina is tenacious and very refractory. Consequently, when two or more ripples overlap, the skin prevents the metal from uniting. It follows from the foregoing that the aluminum bronzes should be poured as quietly as possible, and every care should be taken to prevent the metal being agitated after it has entered the mold."

FILLS MOLD WITH CARBON DIOXIDE

11. An interesting method to reduce the amount of these seams or folds should be mentioned at this point. A long rubber hose is connected with a tank of carbon dioxide gas and, before a large casting is poured, this gas is blown gently into the mold cavities. Carbon dioxide gas, being heavier than air, displaces the air in the mold cavities. As the gas is invisible, burning matches stuck in the risers and sprue holes indicate whether or not the mold is filled with gas. If the mold is full, the flame is extinguished instantly.

12. This operation is done while the pots are being removed from the furnaces. No time is lost in pouring. The casting is poured immediately after the mold has been gassed. Since there is no free oxygen present, no oxide is formed, therefore, no seams or folds are formed in the mold cavity itself. The improvement in the quality of the castings was found to be sufficiently high to justify the continuation of this gas treatment, which is used only in the larger molds.

BALL VALVE PRACTICE

13. Ball valves are an interesting job to cast in aluminum bronze. At first glance, the molding and casting of such a simple

looking part seems to present no difficulties. However, much time and study were required to develop a foundry technique that assured the production of good castings. The ball valve castings are cast solid in two different sizes, one, to machine to 3¼-in., the other to 4¼-in. diameter. The smaller one (Fig. 1) will be described first.

14. The two main causes of imperfections are shrinkage and dross. To overcome the former, cast iron chills are rammed up as part of the drag half of the mold. These chills average about 1-in. thick. Their shape can be readily seen in Fig. 1, two being still attached to the castings and one leaning against the wall.

PRECAUTIONS FOR CHILLS

15. The chills are cast of ordinary gray iron, though for long life a more heat resisting iron such as a steel mix or Ni-resist may be recommended. Care must be taken that the chills are free from any scale, rust and moisture. For that reason, they should be thoroughly sand blasted at least on the surfaces that come in contact with the molten metal. This precaution must be observed every time they are used. No chills should be left in the mold over night.

16. The chills rammed in the molds must be preheated to prevent cold shuts in the castings. A rough but sufficient check of the temperature can be made by touching the chills with the hand. If one can barely touch them, the proper temperature is reached. If they are too hot, they not only dry the sand at the bottom of the mold, thus causing washing, but they defeat the very purpose of a chill. A safe way to preheat these chills is to place hot chunky pieces of steel in them.

17. The mold should be closed only a few minutes before pouring, to avoid any moisture deposit within the mold.

18. As shown in Fig. 1, a specially designed gate is used. A sprue leads into a runner, part of which is in the cope, and part in the drag. The effectiveness of such a runner gate is shown in the picture by the amount of dross that was caught in the cope. The horn gate is connected with this runner by a short gate cut in the drag only. An 8-in. cope is used and a 2-in. diameter riser is placed directly over the casting. To produce 2 balls having a combined weight of 9½ lb. in the machined condition, 32 lb. of metal are necessary. The risers on the ball castings are cut off

about 2 in. from the top and the stem is used to hold the casting in the lathe in which it is being machined.

19. The molding procedure of the large ball (Fig. 2) is similar to that of the small one. Owing to its size and the extra large chills required, it was found best to cast only one casting in a mold. Here again, considerable experimenting was necessary to design chills with which good castings could be obtained.

20. A half chill, similar to that used on the small ball, was not sufficient to produce solid castings. Shrink holes at the bottom of the riser were encountered. A chill completely surrounding the ball then was used, with a small opening at the bottom for the gate and a large hole on top for the riser. At first, the chill extended about an inch up the riser. The neck, meaning the section where the riser joins the casting, was now chilled too much. This caused the casting to solidify there first, thereby separating the still liquid center of the ball from the feeding reservoir of the riser. The result was a shrink pipe on top of the machined casting. The deficiency was finally overcome by reducing the chilled section on the neck to about ½ in.

CHILL TROUBLES

21. The in-gate through the bottom of the chill also gave trouble. If made too long, it froze before the mold filled. If too narrow, it caused the inflowing metal to spout and if too large, it drew back during the solidification and resulted in a drawhole on the finished casting.

22. The gating, chilling and feeding as shown on Fig. 2 are the final and successful methods now used.

23. The most important part of getting good ball valves is the pouring technique. No matter how carefully the mold is made and how strictly all rules regarding chilling, preheating, etc. are observed, defective castings will be produced unless the proper pouring technique is followed.

24. The paramount rule is to maintain one steady stream of metal. It is easy to observe and control the even flow of metal by looking down into the riser. If the metal enters the mold from the bottom in a fountain-like stream, the casting will be defective. One single splutter is enough to cause sufficient dross to render the casting defective. Looking down upon the rising metal, its surface must be perfectly smooth with not a ripple on it.

25. It is evident that under these conditions strainer cores, "choking the sprue", or fast pouring must be avoided.

26. It is, no doubt, interesting to know, that 33 lb. of metal are required to cast one ball weighing 11 lb. machined. This factor is well worth considering when estimating the cost of aluminum bronze castings.

CASTING VALVE SEATS

27. The valve seats that go with the ball valves are shown in Figs. 3 and 4. Two reasons induced us to cast these parts as shown in the illustrations, with the valve seat proper face down; first to secure a flawless surface on the valve seat and second, to facilitate the feeding of the casting with sufficient heavy risers.

28. Both patterns are parted in the middle. The drag half is formed by a dry sand core which also forms the ring gate and the four in-gates. These in-gates are really nothing but simplified small horn gates permitting the metal to rise uniformly at all four points.

29. The small seat (Fig. 3) is fed by a solid riser of practically the same diameter as the casting and the large seat (Fig. 4) is fed by two half round wedge risers. No chills are used on these two castings. The pouring technique is the same as that for the ball castings. Twenty seven pounds of metal are required to produce one valve seat (Fig. 4) weighing 5¾ lb. machined.

VALVE COVER PRACTICE

30. The valve cover (Fig. 5) is the least difficult of all castings to make. Nevertheless, an ordinary gate, such as used for red brass, phosphor-bronze, or gun metal, would result in nothing but drossy and leaky castings.

31. A horn gate is essential to let the metal enter the mold cavity from the bottom with no turbulence whatsoever. A 3-in. diameter riser attached to one side of the casting will feed it during solidification. This riser must be placed close to the opening of the horn gate, otherwise a shrinkage will occur on the concave side of the casting. Tilting the mold with the riser side up will increase the feeding capacity of the riser.

32. The casting is poured slowly with a steady stream of metal, holding the nozzle of the crucible as close to the sprue as possible.

33. The discharge manifold (Fig. 6) is composed of a com-

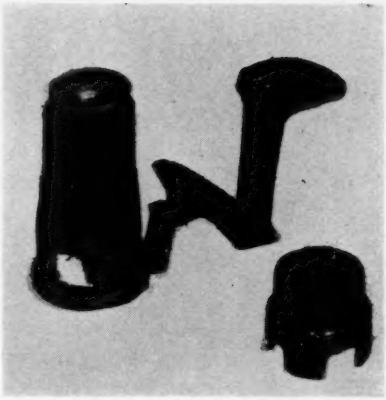

FIG. 3—SMALL VALVE SEAT CASTING SHOWING GATING ARRANGEMENT.

FIG. 4—LARGE VALVE SEAT CASTING SHOWING GATING ARRANGEMENT.

paratively light weight pipe to which are attached on one side an extremely thick disk-like flange and on the other side three heavy square flanges. This difference in wall thickness aggravates the existing tendency of aluminum bronze to crack and shrink in corners. Three good sized risers together with iron chills covering the entire flange sides and every rectangular corner were necessary

FIG. 5—VALVE COVER CASTING WITH GATE AND RISER ATTACHED.

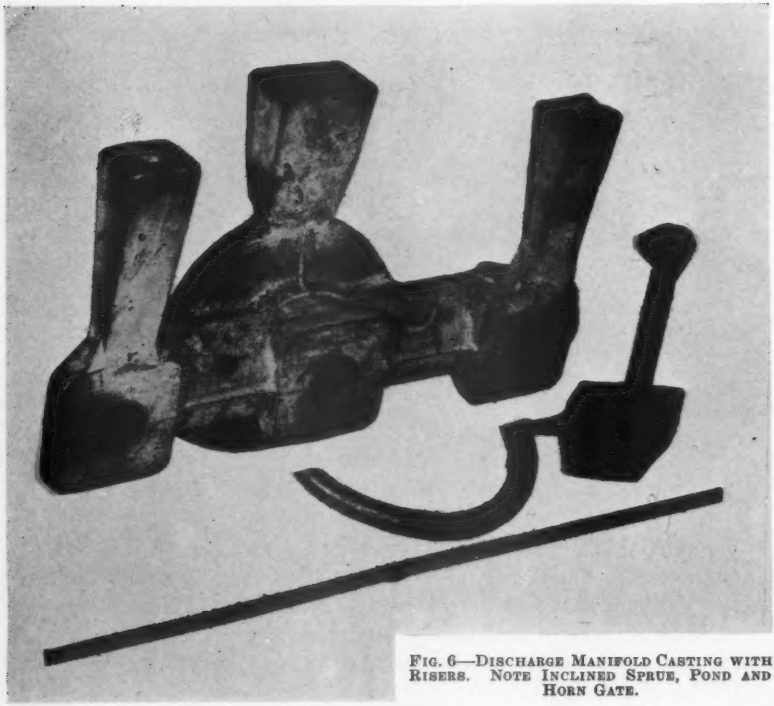

FIG. 6—DISCHARGE MANIFOLD CASTING WITH RISERS. NOTE INCLINED SPRUE, POND AND HORN GATE.

to produce solid castings. These castings must be leakproof under a hydrostatic pressure of 2000 lb. per sq. in.

34. To prevent dross from entering the mold, the metal is not, as in the previously mentioned cases, poured slowly but is choked through a specially designed gate.

METAL PATH.

5. Following is a description of the path the metal takes before it enters the mold cavity. An inclined sprue leads the metal directly into a pond in the joint of the mold. This pond breaks the force of the inflowing metal and is located with two-thirds in the drag and one-third in the cope. As the out-gates or branch-gates are considerably smaller in area than the sprue, the pond will fill up readily, with the dross floating to the top. Clean and quiet metal is drawn from the pond in a spigot-like fashion through the out-gates, running into the horn gates. Fig. 6 illustrates better than words the whole gating method.

36. The horn gate is attached to the lowest part of the casting, in this case, the round flange. As shown in the illustration, the connecting gate is considerably smaller in area than the sprue, enabling an easy choking of the metal in the sprue. On the other side, the narrow outlet of the horn gate is much larger in area than the connecting gate thus permitting the metal to enter the casting gently without a dross-forming sputter.

CYLINDERS

37. All the data previously collected and experiences gained during the production of the smaller aluminum bronze castings were especially valuable when molding and pouring the cylinder casting shown in Fig. 7.

38. The rough cylinder casting weighs 160 lb. After it is completely machined, it is tested under a hydrostatic pressure of 2000 lb. per sq. in. The average wall thickness is ½ in. with some heavy sections being 1½ to 2 in. thick.

39. As mentioned at the beginning of this article, the casting shown in the illustration is a defective one. It was rejected on account of the gassed condition of the metal. It is interesting to see how the liberated gases caused the risers to swell. On one of them, the metal was actually forced to flow over the edge of the riser some time after the pouring had stopped.

40. To overcome the draws and shrink cracks, three large risers and 31 chills are used, of which 20 are in the core and 11

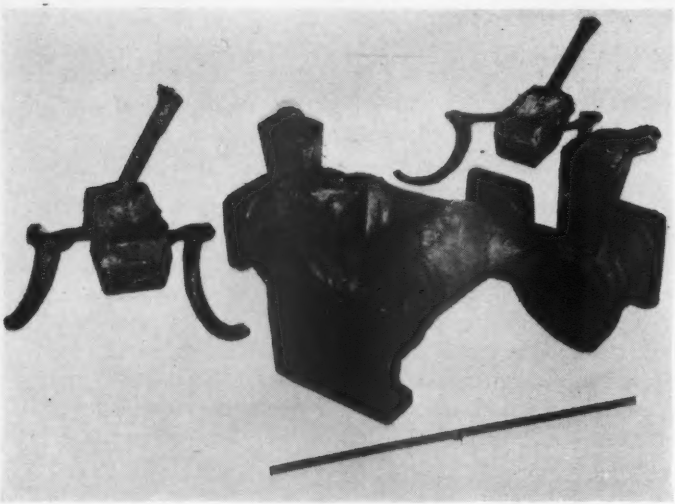

FIG. 7—LARGE CYLINDER CASTING SHOWING GATES AND RISERS. NOTE DROSS IN PONDS.

in the mold. The chills for the mold must be thoroughly sand blasted before they are rammed up. The core chills can be used without being sand blasted as the heat in the core oven will drive off any moisture.

41. The molding sand used is No. 1 Albany and care is taken to keep it on the dry side and avoid as much swabbing as possible. Lake sand of high permeability is used for the cores. As aluminum bronze does not cut in, blacking of the cores is not necessary.

42. Immediately before pouring, the mold is filled with carbon dioxide. The casting is poured two-up with four horn gates supplying the metal from the four lowest points. Here again, the metal flows through an inclined sprue first into a reservoir or pouring pond which is proportionately larger than the one used for the discharge manifold.

43. The horn gates are connected with the pond by small gates that must have a combined cross sectional area that is less than the area of the sprue. This arrangement will permit an easy choking of the sprue.

44. Here is a practical example, the dimensions taken from the gates of the cylinder. The gate is $1\frac{1}{4}$-in. wide and $\frac{5}{16}$-in. thick, having, therefore, an area of 0.39 sq. in. or 0.78 sq. in. for both

gates. The area of the 1¼-in. diameter sprue is 1.22 sq. in. How effective such a mathematically designed gate and sprue arrangement is, can best be seen on the picture by the amount of dross retained in the cope side of the pond. The principle of this special gating is to prevent the metal being agitated after it has entered the mold. In this way the dross is kept down to a minimum.

SUMMARY

45. It is evident from the foregoing that aluminum bronze possesses peculiarities that distinguish it from ordinary non-ferrous alloys and that, as a consequence, it is necessary to handle it entirely different from the ordinary gun metals and red brasses. The main difficulties to be anticipated are drossy metal, piping and shrinkage of heavy sections and draw cracks in the corners of re-entrant angles. However, any type and size of aluminum bronze castings can be successfully cast if made in accordance with well defined principles and certain precautions are adopted which may be summarized as follows:

a. The metal should be poured in a slow steady stream at the lowest pouring temperature at which a complete casting of any one design may be obtained with regularity.

b. The molding sand should be on the "dry-side" and be of a high permeability. The sand must be rammed up uniformly around the pattern and any damp spots, caused for instance by excessive swabbing or patched up corners and lugs, must be avoided. If the metal simmers and fails to lie quietly at any point, it will foam and produce dross.

c. The core sand should be very open, well vented and low in oil bond.

d. All cast iron chills used in the cores as well as in the mold must be free from rust and scale, absolutely dry and in the latter case sufficiently pre-heated.

e. The gate should be so arranged that the metal enters the mold at the lowest possible point or points and in a manner that will avoid the formation of ripples and spurting.

f. Heavy sections must be fed by proportionately large risers to eliminate shrinkage or chills must be used. In some designs a combination of both is effective.

g. Inner corners of re-entrant angles must be well filleted and chilled to avoid draw cracks.

(*Discussion begins on Page 492*)

DISCUSSION

The following discussion includes remarks presented on the papers by Messrs. Hensel and Ganzauge. In absence of the author, Mr. Hensel's paper was presented by Vaughan Reid, Jr., City Pattern Works, Detroit, Mich.

M. T. GANZAUGE (*Introductory Remarks to Paper Presentation*): The purpose of my paper is twofold. Firstly, it is hoped that it will stimulate among foundrymen already successfully engaged in the production of aluminum bronze castings an exchange of ideas, experiences and observations they have made with this interesting metal, and secondly, it is hoped that the detailed description of the production of seven different aluminum bronze castings will in some small measure be an aid to foundrymen who intend to venture into the making of aluminum bronze castings or who have difficulties in producing these castings with a minimum amount of defectives.

The gating, risering, chilling and pouring of the different castings described herein are the outcome of many experiments and tests and were finally adopted by us as standard practice after the scrap losses were found to be 10 per cent and less. This percentage was considerably lowered in subsequent runs of 50 and 100 pieces at a time and frequently the defectives are now as low as 2 per cent.

I mention these figures not to praise our practice, but to prove that defectives can be kept down to a minimum even in aluminum bronze providing certain fundamental rules regarding molding, melting and pouring are strictly adhered to.

DR. G. H. CLAMER[1]: I consider this contribution by Mr. Ganzauge a decidedly comprehensive paper. It is greater in scope than any other single paper on the subject of manganese bronze with which I am familiar.

In the composition given in paragraph 2, the author has quoted standard specifications, such as the A.S.T.M., Navy Specifications, and others. It may be of interest to know that at the Pittsburgh group meetings of the A.S.T.M. a few months ago, I criticized these specifications severely from the standpoint that the minor alloying constituents, if used in anything like the upper allowable limits, make it impossible to produce a bronze having a combination of maximum tensile strength with maximum elongation. I criticized the specification from the standpoint that the manufacturer was unable to obtain this desirable combination of physical properties because of the high minimum specification on zinc content, *vis* 38. With the privilege of reducing zinc content to 36 per cent, it is possible to make a very much superior bronze.

This matter was discussed in Sub-Committee 2, of Committee B-5, A.S.T.M. and the proposal was made to reduce the low limit on zinc to 36. The motion was amended to refer to zinc content as balance instead of giving actual figures. That proposal of Sub-Committee 2 has been favorable by letter ballot, and will come up for action at the June meeting of the Society.

I might call attention to the fact that the so-called super-manganese

[1] President, Ajax Metal Company, Philadelphia, Pa.

bronzes, the high tensile manganese bronzes, with very high content of alloying metals, have zinc content down as low as 24.

There are one or two points on which I do not altogether agree with the author. In paragraph 5, item (e) is a statement that "the charge should, be kept covered with charcoal." I believe in another place, the author recommended an oxidizing atmosphere, and here recommends the use of charcoal. I agree with the statement that "in no case should the charcoal be used in the bottom of a preheated ladle and hot metal poured on top of it." I have seen lots of manganese bronze absolutely ruined by such treatment. Whether that is due to the moisture in the charcoal or to the CO generated, I do not know. At any rate, if you put charcoal, particularly wet charcoal, on the bottom of a pouring ladle, you will get a casting having that characteristic yellow center with which we are all familiar.

The author refers to plaster of Paris, which is calcium sulphate, in combination with charcoal. Theoretically, calcium sulphate should not be broken up by any of the metals contained in manganese bronze except, perhaps, aluminum. It has been my experience, that calcium sulphate, mixed with charcoal, or in contact with graphite of a crucible, is reduced to calcium sulphide, and sulphur from that source enters the metal.

Paragraph 48, the author says: "Manganese improves the elastic limit, but reduces the resistance to shock if present in any appreciable quantity." I can confirm that. I have known of cases of propeller blades of high manganese content which having struck an obstruction were cracked off without difficulty. The cracking, I think, was traced quite conclusively to high manganese. As a result of this observation manufacturers are careful not to use manganese bronze with high manganese content. It is supposed also that high manganese causes pitting.

That is rather at variance however with my original experience in the manufacture of manganese bronze. In the early days, we made manganese bronze with a relatively high manganese content. We used manganese-copper in making it, and our standard formula called for 3.25 per cent manganese, 1.25 per cent aluminum, 55 per cent copper and the remainder zinc. We were able to make bronzes exhibiting tensile strength of 85,000 to 90,000 lb. per sq. in. and elongation of 25 to 35 per cent in 2 in. But whether they were brittle under shock, I don't know. We never had any experience to indicate it.

Recently, I was talking to one of the large propeller manufacturers about the possibility of using cement bonded sand for making propeller blades. Of course, it is highly essential that propellers come out of the mold with extreme accuracy. As a matter of fact, a great many propellers are machined, and if it were possible to get away from the machining and chipping, by the use of cement bonded sand, I think it would be quite an advance in the art of making propellers.

JAMES L. WICK, JR.[2]: I wish to express our appreciation to the authors for these splendid papers. Our experience in aluminum bronzes is

[2] President, Falcon Bronze Co., Youngstown, Ohio.

very limited, and this is a great opportunity for me to get some information.

If these are characteristic of the type of papers that we are going to have at this meeting of the A.F.A., I think we will be well repaid, and the dividends that we receive will more than justify our efforts to be present here.

R. L. BINNEY[3]: It so happens that these two papers are of much interest to us because, while we are not casting a great tonnage of these alloys, we cast them continuously five days a week.

One of the remarks in Dr. Hensel's paper, which I think so well dovetails with this work, and was not enlarged upon was where he referred to the Guillet equivalents—that is, translating the structure of the manganese bronze or aluminum bronze, (complex yellow brasses) in terms of a simple yellow brass. The application of Guillet's theory has been very useful to us. We know the structure of the simple copper-zinc alloy most desired and then obtain this same structure in the more complex brass thus securing the structure wanted with the additional properties acquired by the aluminum or manganese or other added element. I remember, many years ago, when O. W. Ellis and I worked on our complex yellow brasses, we continually resolved to structures of a simple brass. I attempted to carry the principle over to the line of castings we now make, and found that while it was not so simple a problem, I was able to make a series of micrographs to show that there was a relationship existing along the same general theory. The Guillet principle does not work when compounds are formed, but applies until the limit of the element is reached that forms the compound.

Also, in both types of alloys discussed, we have done a little work which I think Chairman Strauss could talk about in a most instructive manner as he cooperated with us in studying the effects of vanadium on alloys such as are discussed in Dr. Hensel's and Mr. Ganzauge's papers. We have introduced various amounts of vanadium by using alumino-vanadium with these two alloys, and really with quite a bit of success. It is, I think, proper to mention this because I doubt if either one of the papers refer to the addition of vanadium. We have found that by introducing vanadium into either type of these alloys, you can vary some of the physical properties, and when you are working toward a definite end, the vanadium content becomes very valuable. If, for instance, you take either one of these alloys and subject them to alternating cycles of heat, you want the largest possible resistance to cracking, oxidation and warping. We have found that the introduction of vanadium is very beneficial in increasing the resistance of these alloys to thermal shock.

I thought that might be one addition to the papers. As vanadium has not been discussed, I think its use should be considered. When vanadium is added, these complex brasses become more dense and their physical properties increase. It would be very interesting to determine the improvement in pressure castings. We have not done this as our work is entirely with heat resisting alloys.

MEMBER: Mr. Ganzauge recommends the use of ingots obtained from

[3] Binney Castings Co., Toledo, O.

a smelter in the manufacture of aluminum bronze. I want to ask if he has had any experience in producing aluminum bronze castings by the hardener method; that is, by obtaining an aluminum iron-rich alloy of copper that is mixed in with the copper in percentages of perhaps 20 per cent. In other words, instead of using the ingot, have you used the hardener? That is the first question.

A second question: Can Mr. Ganzauge show us briefly, how he would gate an aluminum bronze casting, one on the order of a bushing 3-in. outside diameter, 2-in. core, 12-in. long; the other in the shape of a disk about 14-in. diameter and 2½ in. thick.

MR. GANZAUGE: Answering the first question, we have made aluminum bronze ingots ourselves, and then used these ingots after the analysis was established to produce aluminum bronze castings. But I am frank to admit that the success was rather doubtful. Frequently the mixture was not according to the analysis, and we had difficulties in added shrinkage. We therefore finally decided to buy this metal from a refiner who guaranteed their analysis. We buy them in carload lots and all our troubles are thereby eliminated as far as getting incorrect analyses is concerned.

In regard to the second question, I think it would be best, since the time is limited, if I am permitted to answer it at the round table discussions.

SAM TOUR[4]: The subject of melting and alloying is one thing that should never be lost track of in connection with aluminum bronze. This paper that has been presented is very interesting. It starts with the pouring and carries on through casting, but it does not cover the alloying and melting process. It has been my experience that many castings are ruined in the melting. Many castings are ruined by attempts to make the alloy and pour direct. Experience has taught that the aluminum bronze alloy must first be made and ingoted and then remelted. It is usually not possible to make the alloy in the pot and pour castings direct and get good castings.

In the melting process itself, it is very necessary to avoid gassing. The paper this morning referred to gassing from the use of charcoal. Charcoal is not the only thing that may cause gassing of aluminum bronze. It would seem that the authors are using an oxidizing atmosphere in melting and, therefore, they have no particular difficulties with gassing. Those who attempt to melt aluminum bronze in a reducing atmosphere, or what some people try to call a neutral atmosphere, do have a lot of trouble with gassing. The melting process itself is very important and it must not be carried out in a reducing, or so-called neutral atmosphere.

[4] Lucius Pitkin, Inc., New York, N. Y.

Cleaning Steel Castings

By Paul A. Dougher,* East Chicago, Ind.

Abstract

In the discussion of the above subject, the author explains the proper use of labor, stating that proper organization is necessary to secure the greatest production from the most skilled employes. He then explains how pneumatic chipping is done, how the proper equipment is selected, testing of chipping hammers and steel for the tools used. The second portion of the paper is devoted to a discussion of the results obtained on grinding wheel tests by the company with which he is connected. In this connection, he explains how grinding wheel tests are conducted and describes a method used to keep the peripheral speed of the wheels within certain limits as the wheels wear. The final section of the paper is devoted to a discussion of the various pieces of apparatus used for abrasive cleaning and the author states that his company hopes soon to be able to utilize a water method for cleaning its castings.

1. In its simplest form, the cleaning of castings may be defined as the removal of surplus metal and facing and core sand adhesions.

2. Until within the past few years, the operation of cleaning castings has not had the benefit of research and investigation that has been devoted to the metallurgical, molding and core departments in respect to their many practices, such as heat treatment, sand control, etc.

3. The methods used in cleaning have not changed much fundamentally, but have been mechanized and such mechanical means improved and more effiectively used. If this division of foundry practice is to improve, a greater amount of engineering knowledge and research must be devoted to its many operations.

4. As the firm with which the author is connected is a company with many plants producing castings weighing from a few ounces to many tons and in lots of one casting to many thousands from a single pattern, we have all types of cleaning problems. Our several plant organizations have devoted time and thought in their investigation and research of these problems, exchanging the valuable information and data so obtained. The reason for

* Engineer, American Steel Foundries.

Note: This paper was presented at a session on Steel Founding at the 1936 A.F A. Convention, Detroit, Mich.

these researches and investigations is primarily an economical one, but improved product and working conditions are also considered.

5. In the past, we have devoted considerable time to these investigations in respect to chipping and grinding and more recently to the cleaning of castings by blasting. Our investigations have led to the selection of proper equipment, methods, and general practice best suited to our operating needs, resulting in savings in costs, improved quality of product and better working conditions.

PROPER USE OF LABOR

6. Those who have been long in the industry will recall the practice of many years ago of the foundry foreman handing a pattern to a molder with only the instructions, "Joe, make one off this." The molder was required to locate a suitable flask in the yard, secure gaggers, head forms, and gate pieces before he was ready to function as a producer.

7. This practice was found uneconomical as a skilled direct producer was being used to do work that a lower cost indirect workman could perform as well. The present day practice is to have all this work previously planned and done by laborers and the new job ready for the direct producer before he completes his present assignment. One would not pay $0.80 per hour for $0.40 work but this is actually being done when a skilled laborer is permitted to perform duties that can be done as well by a lower priced employee.

8. What is true in reference to keeping direct labor gainfully employed by giving them service applies in a greater measure to the equipment which the direct producer uses. Hardly any piece of equipment costs less per hour to operate than the wages paid its operator. The expenses which follow a piece of equipment are insurance and taxes, depreciation, repairs, and power. The need of keeping equipment serviced so that it may be continuously used on production work is, therefore, quite evident.

CHIPPING

9. The research and investigation given to chipping brought out the need not only of proper equipment but service to direct laborers as well. This service in respect to chipping was confined to designing, standardizing, and locating benches, casting trays,

etc., and the segregating of castings of the same pattern so that the direct workers became most efficient because of repetitive work.

10. The size and location of the gates, risers, fins, etc., and quite often the design of the casting itself are factors which determine the means that must be employed in the chipping operations. The average run of castings can be most economically chipped by the use of pneumatic chipping hammers of the right size and kind, and with hammer chisels of proper physical and chemical properties.

Selection of Chipping Hammers

11. In the selection of chipping hammers suitable for our own use, we conducted numerous tests, by actual usage in the shop, of various styles and makes and from such experience selected the most suitable capacity. Following this, several makes were compared in regard to such tangibles as weight of the hammer, air consumption, number of blows per minute, and the force of the blow; and in regard to such intangibles as vibration and general versatility. The force and number of blows per minute establish a basis of comparison of the work performed by the different makes; the air consumption, a comparison of operating costs. There is also another important factor that must be considered and that is maintenance. It was found that minor repairs such as replacing bushings and throttle levers, and refitting worn cylinders with over-size pistons were all the minor repairs that could be satisfactorily performed by ourselves. All other repairs have been referred to the manufacturer of the hammer.

12. The type of hammer most suitable for our general use was one which operated at 85 lb. air pressure giving us a satisfactory force with a frequency of 2400 blows per minute and a stroke of 2 in. with an economy of 16 cu. ft. of air per minute. This hammer weighs approximately 12 lb. and is about 12 in. over-all.

Testing Chipping Hammers

13. Chipping hammers are tested by the following method: The hammer is clamped in the vise of the testing apparatus with the piston hammering a plunger attached to a hydraulic receiver. A pressure gauge attached to the hydraulic receiver operates a recorder that prints a continuous curve of the force of the hammer. The imprinted paper is graduated so that the number of blows a

minute may be determined by counting the pressure peaks. Air is admitted to the cylinder of the hammer from a calibrated air reservoir the pressure of which is maintained by water. From the time of operation and the air used, the cubic feet of air used per minute is known. The force as indicated by the imprint on the paper may be compared with the curve of other hammers or may be calculated from the weight and stroke of the piston.

14. The selection of suitable tool steel for chisel blanks should not be overlooked if this expense is to be kept under control. The elimination of tools, marked and noted, that are too soft or too brittle will by trial establish a physical and chemical specification for each specific operating condition.

15. It has been found more economical to use forged to shape steel for standard chisels and plain forged steel for special shapes. These are purchased with a round shank, it being found more convenient than hexagonal shank, for use on such a miscellaneous class of work as we do.

GRINDERS

16. A number of years ago, the slow speed vitrified wheel was being replaced by the high speed rubber and bakelite bonded wheels in regard to certain types of grinding. With the ever present problem of reducing costs, we obtained equipment on trial. We removed superfluous direct and indirect labor that was heretofore unnoticed and with re-location of machinery, re-location of cleaning room space, improved floor conditions, boxes, trays, etc., costs immediately dropped.

17. Based on tests made, ten swing grinders, mounted from fixed points, with a radius of operation of two feet front and back, and three feet to either side were replaced by three high speed swing grinders mounted on electrically driven side wall cranes that could cover a space 60 ft. long and 20 ft. wide. The whole machine was hung so that its radius of operation was 360 deg. with an up and down movement of 8 ft.

18. With this equipment and with grinding wheels chosen by results of tests on high speed grinding wheels, the grinding cost was reduced almost 60 per cent, and production increased almost 500 per cent per direct laborer. Satisfied that we had the best equipment, we tested many makes and types of high speed wheels to establish and reduce the cost of grinding. Trial wheels were tested and compared with a standard wheel.

Table 1

SAMPLE GRINDING WHEEL REPORT

Date.....

Make	
Size	
Grade & Grain.....	
Grinder	
Maximum Grinding Speed.....	f.p.m.
Minimum Grinding Speed.....	f.p.m.
Average Grinding Speed.....	f.p.m.
Available Abrasive	cu. in.
Original Weight	lbs.
Final Weight	lbs.
Used Abrasive	lbs.
Weight of Wheel per Cubic Inch.....	lbs.
Original Volume	cu. in.
Final Volume	cu. in.
Used Abrasive	cu. in.
Cost of Wheel.....$	
Cost of Wheel per Available Cubic Inch.....$	
Cost of Used Abrasive.....$	
Metal Removed	lbs.
Metal Removed per Pound of Abrasive.....	lbs.
Contact Grinding Time.....	hrs.
Total Grinding Time.....	hrs.
Operating Cost per Hour.....$	
Operating Cost .....$	
Overhead Cost per Hour.....$	
Overhead Cost .....$	
Total Grinding Cost.....$	
Operating Cost per Pound of Metal Removed.....$	
Overhead Cost per Pound of Metal Removed.....$	
Abrasive Cost per Pound of Metal Removed.....$	
Cost per Pound of Metal Removed.....$	
Metal Removed per Cubic Inch Abrasive.....	lbs.
Metal Removed per Hour.....	lbs.

Remarks:

.....

Tester.

19. The two important factors that influence the purchase of grinding wheels are the cost per pound of metal removed and the metal removed per hour. The metal removed per hour insures production and the cost per pound of metal removed gives the cost comparison.

Testing Grinding Wheels

20. A wheel is tested in the following manner: A record is kept of the total elapsed time and the contact grinding time. The wheel is measured and weighed before and after grinding. All castings are weighed before and after grinding, giving the amount ground. Knowing the cost of the wheel, the overhead and operating costs, we can easily calculate the total grinding cost and the removal per hour.

21. We have tested wheels running as high as 42 lb. of metal removed per hour with a cost as low as $0.055 per lb. of metal removed. We must, however, in production use a wheel slightly harder than this so that an excess of fins and sharp corners would not increase our costs of wheels too much. As the old practice gave us 8 lb. of metal removed per hour with a cost of $0.169 per pound of metal removed, our practical savings in cost amount to about 60 per cent with production increased about 500 per cent. A sample grinding wheel report is shown in Table 1. Similar tests were run on stand grinders with a similar decrease in costs and an increase in production.

Grinding Wheel Speeds

22. One factor that maintains the high rate of removal is the speed of the grinding wheel. The safe speed of the bakelite bonded wheel under our operation has been set at 9000 ft. per min. We have tried to keep this speed below 8500 ft. per min. and still maintain a high average peripheral speed during the entire life of the wheel. As the reduction in the size of the wheel necessarily means the reduction in peripheral speed when run at a constant revolutionary speed, we have established points where the motor shaft pulley on swing grinders is changed to increase the speed of the wheel. We have economically selected four pulley changes while a 24 in. diameter wheel is reduced to 15 in.

23. With a constant speed motor running at 1800 r.p.m., the peripheral speed of the wheel varies as shown in Fig. 1. On

stand grinders, the speed is set at the stand, and the wheels, as they reduce in size, are moved to a stand of greater r.p.m. This does not affect the abrasive cost per lb. of metal removed but the speeding-up of production decreases the operating and overhead cost per lb.

SAND BLASTING

24. To effectively remove cores and clean castings of sand adhesions, to improve appearance, or to prepare the castings for burning off heads, painting, machining, or assembling, we must use a sand or shot blasting method.

Abrasive Blasting Machines

25. There are a number of machines and methods to effectively accomplish this. For small castings weighing up to about

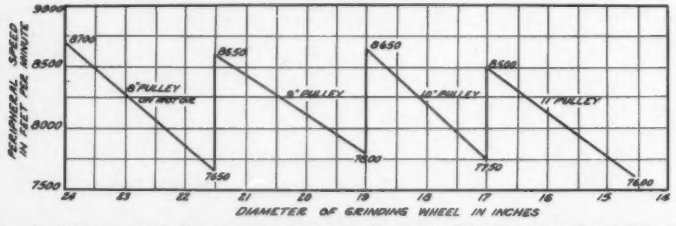

FIG. 1—VARIATION IN PERIPHERAL SPEED OF GRINDING WHEEL WITH DIAMETER OF WHEEL. CHART SHOWS HOW PERIPHERAL SPEED IS KEPT FAIRLY CONSTANT ON SWING GRINDER BY INCREASE OF MOTOR SHAFT PULLEY SIZE.

50 lb., probably the most satisfactory method is a tumbling arrangement of sand blasting. The castings, while tumbled, are sprayed by sand.

26. The air sand blast tumbler, known as the tumblast, finishes a load of approximately 1500 lb. in about 8 minutes, depending to an extent on the design of the castings. This machine is of the endless belt tumbling type, and being reversible, is self-dumping. The advantage of this type of machine is that unskilled labor may be utilized to load it. The operator may then control more than one machine.

27. Another type on this same design eliminates the air fan and actuates the sand by a rotary centrifugal action impeller. This eliminates to some extent the dust in the foundry due to seepage from the machine, and reduces the size of the classifier and dust collector that is required to reclaim the sand from the high velocity air.

28. Another type, with the tumbler of a barrel design, has also proved satisfactory. The sand in this tumbler is centrifugally impelled rather than blown in by air. The barrel is self-dumping with a semi-automatic loader attached. This arrangement leaves the operator free to prepare the succeeding load.

29. The sand blast house in which the operator is enclosed with his work, is familiar to every foundryman. It is quite an investment with its dust collecting and ventilating systems, sand reclaimers, etc.

30. The danger of working in the sand blast house has been alleviated by the use of dust respirators and helmets to the point where the dust count of the air breathed by the operator is negligible. For large castings, the operator may blast from without the room, but medium-sized castings, too small for this method and too large for a tumbling method, may be blasted in a little different manner.

Water-Blasting Machines

31. From tests run on an experimental apparatus for more than a year, we hope to eliminate the dust menace with an even less expensive installation than the air sand blast. There are now two production installations differing in detail a little but of the same principle in operation. This apparatus, known as the "Hydroblast," is similar to the air sand blast, the main difference being the use of water instead of air as a sand impelling force.

32. Wet sand is sucked through the gun on the Bernoulli principle by high pressure water of about 750 lb. per sq. in. The fine sand (below 10 mesh) and the coarse (above 40 mesh) are washed out by the waste water. The capacity in lb. of sand per min. has equalled the capacity of the air sand blast and the water sand blast is even more effective in removing cores as the velocity of water assists in washing out baked sand.

DISCUSSION

CHAIRMAN J. H. HALL[1]: The cleaning room, when I first went into the foundry, was the last place on earth any of us wanted to go. But this paper gives us an impression of the amount of work which is being done in that field by engineers today.

J. M. SAMPSON[2]: Have these new vitrified wheels been so improved that they will compete with the rubber bonded wheels? I am a little bit out of touch with the situation, but I know at one time 8 or 9 years ago, the rubber bonded wheels were running away with the market.

MR. DOUGHER: There are some places in foundry practice where a vitrified wheel is better than a rubber bonded wheel; and there are some places where a decreasing cost will be shown by turning to a rubber bonded wheel. A rubber bonded wheel, in my opinion, will perform better on a miscellaneous lot of work where they are grinding fins one time, flat pads another, while the vitrified wheel will work better on flat pads.

CHAIRMAN HALL: That applies to carbon and alloy steels, or chiefly carbon?

MR. DOUGHER: We are acquainted mostly with an alloy steel and with high carbon steels. Most of these tests were run on such types of castings.

MEMBER: Mr. Dougher spoke about the pounds removed per hour with the wheel. I believe he said 40 some odd pounds. I would like to know whether that is the contact time or the regular time of running all the wheels?

MR. DOUGHER: We base the removal on the contact grinding time. That figure was the specific poundage on a specific kind of casting.

MEMBER: We kept track of the number of pounds removed for 5 years, not on contact time but on the basis we were operating, because we were paying for pounds removed and we used to average about 16 or 17 lb.

MR. DOUGHER: That is good. We have set a standard based on operating time, and the standard wheel is close to what you mentioned. On all wheels that we take in for trial, payment is made in their relation to the standard wheel.

MEMBER: What have you found to be the best general purpose hammer for your class of work—for castings weighing from a few ounces up to several tons? Or do you use larger hammers having the 3, 3½ or 4-in. stroke for the heavier castings?

MR. DOUGHER: The plant with which I am connected makes miscellaneous castings. For this type work, we try to standardize on equipment the best we can. The chipping hammers have a 2-in. stroke. The general run of castings weigh, on the average, about 30 lb.

MEMBER: You do find that a 2-in. hammer is satisfactory, I presume,

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[1] Technical Assistant to President, Taylor-Wharton Iron & Steel Co., High Bridge, N. J.

[2] Foundry Engineer, General Electric Co., Schenectady, N. Y.

on chipping with fins having a thickness of an ⅛ to ¼-in. on your larger castings?

MR. DOUGHER: When they get up to that size, we usually mark them with a chipping hammer and then sledge them off.

MEMBER: In your comparison of 2-in. chipping hammers of different makes, did you find any noticeable difference?

MR. DOUGHER: In the amount of air consumption, there was no exceptional difference. I would say it varied anywhere from 16 up to as high as 19 cu. ft. of air per min. The design of the chipping hammer entered into the selection of the specific one that we chose. That is, the cost was not the only item of choosing the hammer. We also had to have one with low maintenance.

MEMBER: Mr. Dougher says they use hammers with a 2-in. stroke. Is it the piston type, or did you try the so-called ring type?

MR. DOUGHER: The hammer we use has a 2-in. piston stroke and is of the ring-valve type.

MEMBER: About 7 or 8 years ago, one equipment company was developing hydraulic blasting. At that time, a number of us were interested, but we were a little afraid of the maintenance cost of the equipment on account of the action of the water. I would like to know whether that method is being generally used now, or not.

MR. DOUGHER: The only part of this hydraulic equipment that will wear out is the high-pressure pump and that operates on pure water, as pure as you can get it from the city, and the gun itself through which the sand is sucked. The nozzles of the gun are made of rubber, similar to some sand blast installations, and therefore the cost of maintenance is low. As the tube through which the sand is sucked is under no pressure at all, an ordinary garden hose may be used for that purpose, which also is low in maintenance. So I believe the maintenance on the hydraulic equipment is practically negligible.

CHAIRMAN HALL: Do you use any carbide nozzles, like they do on sand blasting?

MR. DOUGHER: We have never tried them; we have used only the rubber nozzles.

P. E. MCKINNEY[2]: I am very much interested in the economic feature that is being discussed. It seems to me that this is one feature that can be advantageously considered in a study of cleaning methods. Having the facts and figures before you, it is possible to make improvements in the process of cleaning which will reduce the ultimate cost of casting.

In the old days, it was a case of getting the casting out and sending it out to the cleaning shed without all the regard we should have had for the cost of removing the superfluous materials, such as brackets, excess metal and adhering sand. I believe that the one outstanding advantage in studying cleaning costs and cleaning methods has been to guide us in giving

[2] Metallurgist, Bethlehem Steel Co., Bethlehem, Pa.

constructive suggestions to the designer for slight changes which may permit the elimination of a lot of brackets, the elimination of excess metal at places where it has to be removed in the cleaning, chipping or subsequent machining operations, and a study in the foundry itself of reducing the likelihood of adhering sand by a greater study of our sand methods.

On every study I have seen of sand improvement, the adherence of sand to the castings has immediately come up. These methods of studying cleaning cost have put into tangible form just what it means and have permitted the sand research man to turn into real capitalization his efforts in improving sand and preventing the adherence of sand to castings.

CHAIRMAN HALL: I am interested in what Mr. McKinney has just remarked, that in the long run it is very often the case that economy in the cleaning rooms starts in the pattern shop, and in the foundry.

Metallographic Changes During Cooling Between the First and Second Stages of Annealing

H. A. SCHWARTZ* and C. H. JUNGE,† Cleveland, Ohio

Abstract

The authors offer a series of pictures illustrating the changes taking place while malleable cast iron is in the temperature range through which it passes between the two stages of the well known annealing process. It is shown that ferrite forms by two distinct mechanisms. The growth of ferrite bull's eyes receives some attention and the rather unexpected effect of cooling rate above A_1 on the structural fineness of pearlite and ferrite are illustrated. The relatively rapid reaction rate to be expected just below A_{r1} stable seems to be confirmed. A relation between the size distribution of temper carbon grains and cooling rate above A_1 is pointed out.

1. The authors hope that they will not be accused of "rediscovering the obvious" if they record here certain metallographic observations made in connection with a very old process. If a saturated solution of iron, in the presence of carbon and the other elements commonly occurring in malleable cast iron, is cooled from such a temperature as, say 900° C. (1650° F.), to below A_{r1} point, to 675° C. (1245° F.) for example, it is perfectly correct to say that, given sufficient time, the remaining agraphitic carbon will be converted into ferrite and temper carbon. The statement is, however, highly inadequate as to the details of a most interesting series of transformations which might be involved in the process.

2. An investigation of the successive steps occurring in this transformation on a rigidly scientific basis, carefully separating each variable from any other, would consume more time than the authors had at their disposal for this project and would also result in so complex a report as to be of little use to the foundry-

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man reader. We propose, therefore, to give, in narrative form, a description of some portions of our observations on the metallographic changes taking place, illustrating our discussion by a series of micrographs.

3. In the interest of brevity and accessibility, the essential details for each photograph are recorded in its caption and not repeated in the body of the paper. We hope thus to avoid distracting the reader's attention from the continuity of our story while he absorbs details of heat treatment and so on which must be included for purposes of record.

4. We do not always record chemical compositions of the specimens, for our illustrative material was gathered at intervals from many heats. The observations recorded are probably not specific to any particular metal but occur generally in such white irons as are suitable for the manufacture of malleable castings by the usual methods. Some observations regarding the relation between the location of temper carbon dots and ferrite grain boundaries on the one hand and the dendritic austenite-cementite freezing pattern on the other, have already been described in a paper[1] presented to this Association in 1934.

5. Consider first the consequences of the double iron-carbon constitutional diagram. If an alloy in equilibrium at a point on the A_{gr} line be instantaneously cooled, further graphite separation will be suppressed and the gamma-alpha iron transformation depressed say 400° C. (720° F.) and martensite or some very similar phase will result. Micrographs illustrating this condition are frequent in the literature.[2]

6. If cooling be sufficiently slow, the alloy will reach A_{r_1} stable with the agraphitic carbon concentration of the stable eutectoid. If the cooling continues, not too rapidly to below A_{r_1} metastable, pearlite in corresponding amount separates and below that temperature the pearlitic cementite ultimately decomposes into ferrite and graphite.

7. In the 15° C. (27° F.) interval between the stable and metastable A_1 points, conditions are somewhat obscure. Here the remaining agraphitic carbon is less than enough to saturate the metastable solid solution but in the stable system carbon is practically insoluble and ferrite is the stable iron allotrope. In a

[1] Schwartz, H. A., and Junge, C. H., *"A Note on the Metallography of Ferrite in Malleable Cast Iron,"* TRANS. A.F.A., vol. 42, pp. 94-100, (1934).

[2] Schwartz, Payne, Gorton and Austin, *"Conditions of Stable Equilibrium in Iron-Carbon Alloys,"* TRANS. A.I.M.E., *vol.* 68, p. 916 (1923).

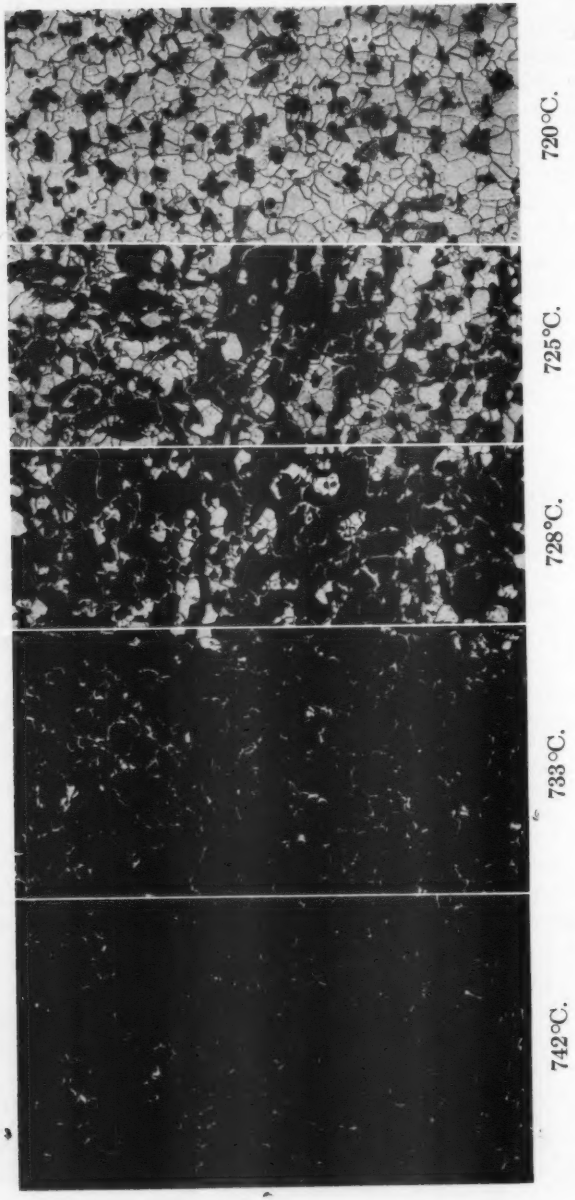
long time in this interval, the solid solution existing just above A_{r_1} stable would decompose into ferrite and graphite. What phases exist before this reaction is complete seems not to have interested the metallographers greatly. One might expect to have a solid solution[3] progressively decreasing in carbon as graphite crystallizes out.

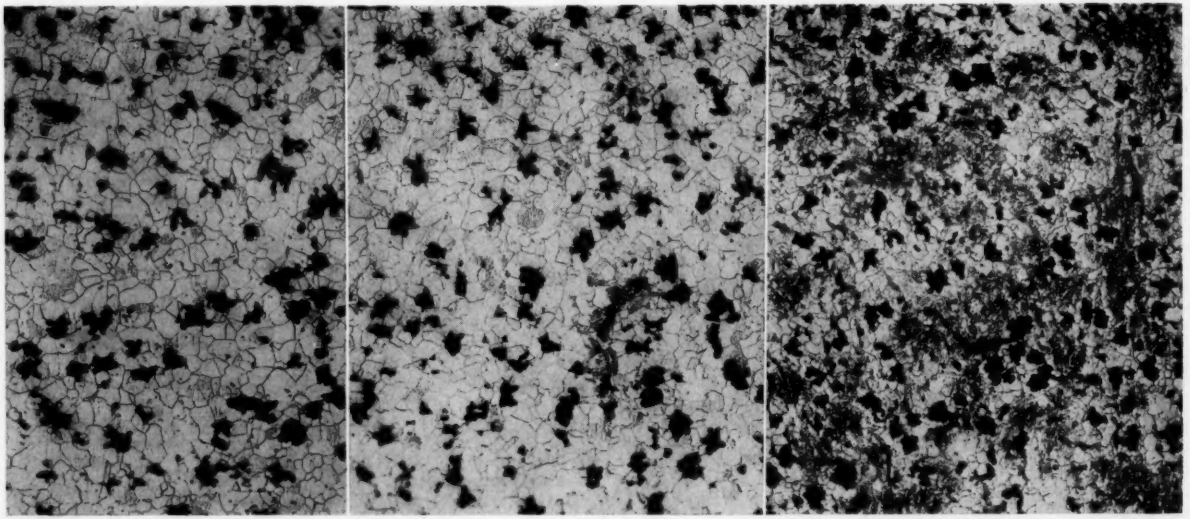
8. The limiting concentrations of carbon in austenite are quite definitely fixed and we might have the simultaneous separation of graphite and ferrite. For moderately rapid cooling from the higher temperature, the solid solution might become supersaturated toward graphite, or under favorable conditions, even toward cementite. In the latter case, the separation of proeutectoid cementite and finally of pearlite would be anticipated. In practice the matter is further complicated by the micro segregation of silicon, manganese and phosphorus as previously described by the authors (*loc cit.*).

9. The phases appearing at various temperatures near the critical range are well shown in Fig. 1. This is a mosaic of the structure of a specimen held (after the destruction of primary cementite) for 3 hours in a furnace having a temperature gradient from 785° C. (1440° F.) at one end of the specimen to 670° C. (1240° F.) at the other end, the change of temperature being at the rate of about 9° C. per cm. A portion of the hot end of the specimen showing homogeneous martensite is omitted. It appears that ferrite first becomes visible in that zone which was at about 740° C. (1364° F.). At this temperature and down to about 730° C. (1346° F.), the ferrite maps out grain boundaries (of gamma iron?). At about 730° C. (1346° F.) bull's eyes of ferrite form surrounding the temper carbon dots and these ferrite areas *increase* in size with *decreasing* temperature until at 720° C. (1328° F.) only vestiges of quenched solid solution (pseudo martensite?) remain. From this temperature down to about 705° C. (1300° F.) only ferrite remains while from about 700° C. (1292° F.) down we have ferrite and pearlite, the latter tending to spheroidize by surface tension. At these low temperatures, the ferrite shows considerable tendency to a bull's eye structure though not so well defined as at (say) 725° C. (1337° F.).

10. We point in passing to the discontinuously rapid graph-

[3] We refrain from discussing here the disputed question whether the stable and metastable solutions are alike in kind. While recognizing that contrary evidence may exist the authors happen to regard it as more likely that two kinds of solution exist.


720°C.
725°C.
728°C.
733°C.
742°C.



717 to 707°C. 702°C. 682°C.

PAGES 4 AND 5—FIG. 1—100X, ETCHED IN NITAL. WHITE CAST IRON CONTAINING CARBON, 2.30 PER CENT; SILICON, 1.20 PER CENT; MANGANESE, 0.29 PER CENT; PHOSPHORUS, 0.157 PER CENT; SULPHUR, 0.049 PER CENT.
A_{c3} STABLE 787° C. (1450° F.); A_{c1} METASTABLE 770° C. (1415° F.); A_{r1} METASTABLE 712° C. (1315° F.); A_{r1} STABLE ILL DEFINED. HELD 4 HOURS IN DRY NITROGEN AT 975° C. (1785° F.) AND SUBSEQUENTLY HEATED 3 HOURS AT TEMPERATURES NOTED AND QUENCHED. (MICROGRAPHS REDUCED ABOUT ONE-FOURTH IN REPRODUCTION.)

itization at temperatures between 705° C. and 720° C. (1300-1328° F.). If the holding time in the gradient furnace be decreased to one hour the ferritic zone of Fig. 1 disappears. Beginning at the cold end we then have in addition to temper carbon throughout: ferrite + laminated (not spheroidized) pearlite, ferrite + laminated pearlite + pseudo-martensite, ferrite + pseudo martensite, the ferrite decreasing with temperature, and finally psuedo martensite alone. The ferrite + laminated pearlite + pseudo martensite zone corresponds in position approximately to the completely ferritic zone of Fig. 1.

11. From the evidence of the 3-hour heat treatment, it would appear that all parts of the metal in this zone were below A_1 stable and some were below the A_1 metastable temperature or laminated pearlite would not have existed and that other areas were at least above A_1 metastable or martensite (or possibly its pseudo morph) could not exist. This structure can not result from the quenching of the stable solution (boydenite) for if we were in the temperature range (above A_1 stable) where this can exist, it would not have been destroyed in 3 hours. The destruction of pearlitic cementite with time in this zone is merely a graphitization phenomenon.

12. It is perhaps difficult to superimpose, on the temperature scale, two sets of observations obtained in this manner for the temperatures were arrived at by interpolations[4]. We have tried to determine relative temperatures as accurately as the circumstances permit but do not regard them as quite as reliable as though the temperature of each micro section had been independently measured. We point to this uncertainty for the zone which here on metallographic grounds lies between A_{r_1} metastable and stable is apparently about 20° C. (36° F.) too low in relation to the observed critical points of the metal. We are not prepared to say that this difference is real and not a matter of observational error.

13. The formation of ferrite on grain boundaries or as bull's eyes, apparently as a function of temperature, is not without interest. Fig. 2 shows that even prolonged heating does not cause this network to represent any great amount of metal. Planimeter estimation by cutting out of large scale photographs, the ferritic and martensitic areas and weighing them[5] suggests that the ferrite

[4] The transfer of a specimen containing numerous thermocouples from one furnace to another and to a quenching bath seemed scarcely feasible.

[5] The grain boundary distribution does not lend itself well to the use of the intercept planimeter.

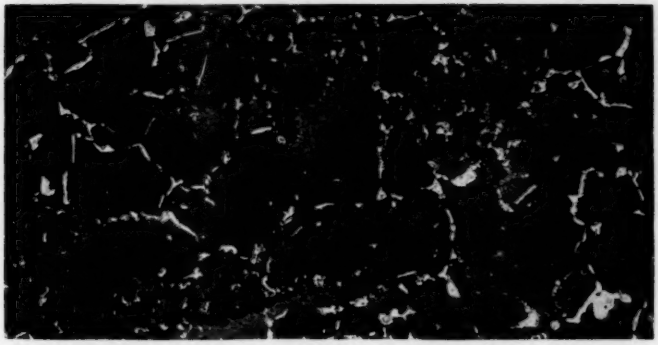


FIG. 2—100X, ETCHED IN NITAL. WHITE CAST IRON HELD TO EQUILIBRIUM IN DRY NITROGEN AT SOMEWHAT ABOVE 900° C. (1650° F.) AND SUBSEQUENTLY 20 HOURS AT 755° C. (1390° F.) FOLLOWED BY WATER QUENCHING.

is roughly 10 per cent of the total *metallic* area and it does not increase materially with time[6].

14. The separation thus evidently occurs above the A_{r_1} stable temperature of the rest of the specimen. It may thus be due to micro segregation of other elements. Owing to the difficulties connected with slow reaction rates of pure binary alloys, we do not yet know whether the same phenomenon can occur where no such micro segregation is likely.

15. A comparison of Figs. 3, 4 and 5 approaches the problem from a different viewpoint by showing a single area of a given specimen when in that stage where the ferrite boundaries exist and after completion of graphitization, etched to show the grain boundaries of the ferrite and etched to bring out the original dendritic freezing pattern. The structures are somewhat complicated and it is difficult to mentally superimpose one upon the other.

16. Fig. 6 is a line drawing superimposing the original ferrite network (in black) upon the boundaries of the ferrite grains after completion of graphitization (thin lines) and the temper carbon dots (cross hatched). It was found impossible to superimpose these pictures photographically partly because of the confusion arising from etching pits in the gigantic ferrite grains and partly from the impossibility of getting the ferrite mesh work, even if printed as a negative, to contrast with both the grain

[6] If A_3 stable were below A_2 metastable the ferrite net might represent the excess of iron corresponding to the lower solubility of carbon in boydenite as compared with austenite. The senior author has from time to time seen other indications that A_3 stable is the lower but thermodynamic calculations seem to indicate the contrary.

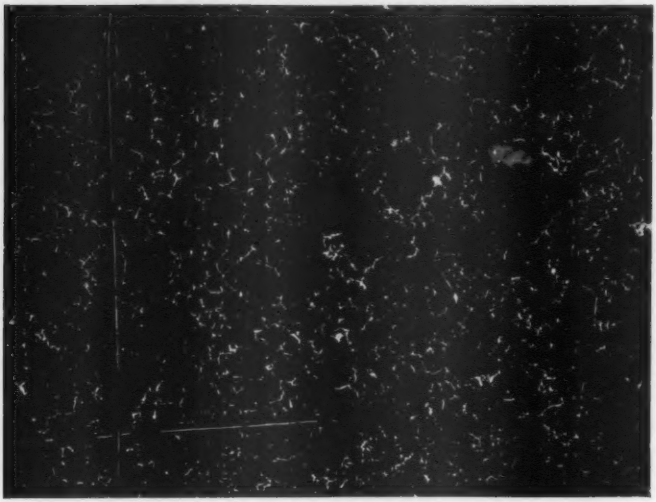


FIG. 3—35X, ETCHED IN NITAL. WHITE CAST IRON HELD TO EQUILIBRIUM ABOVE 900° C. (1650° F.) AND SUBSEQUENTLY IN THE TEMPERATURE RANGE PRODUCING FERRITE GRAIN BOUNDARIES SUFFICIENTLY TO DEVELOP THESE NEARLY COMPLETELY.

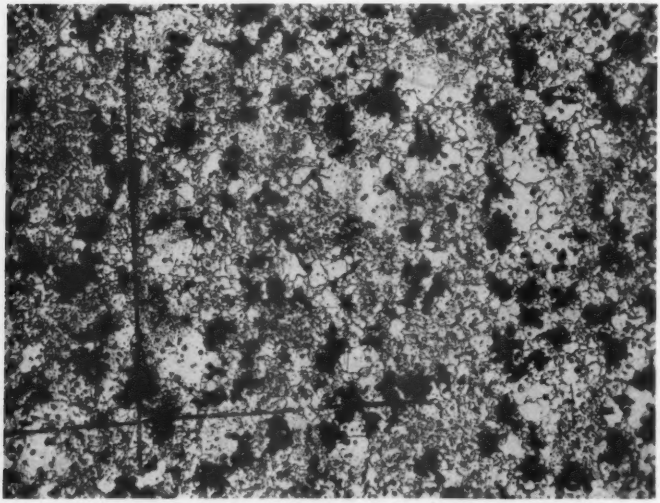


FIG. 4—35X, ETCHED IN NITAL. IDENTICAL SPECIMEN AND FIELD OF VIEW WITH FIG. 3, GRAPHITIZED TO COMPLETION BELOW A_1 AND ETCHED TO DEVELOP GRAIN BOUNDARIES.

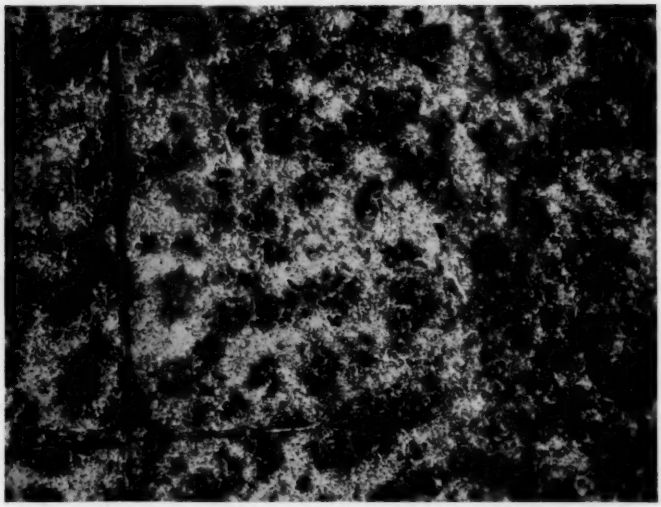


FIG. 5—35X. ETCHED IN ALKALINE PICRATE. IDENTICAL SPECIMEN AND FIELD OF VIEW WITH FIG. 3, GRAPHITIZED TO COMPLETION BELOW A_1 AND ETCHED TO DEVELOP DENDRITIC SEGREGATION.

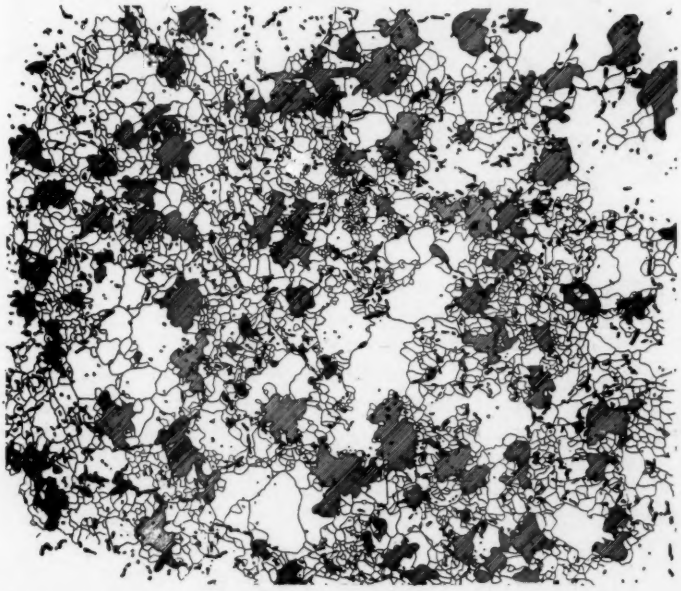


FIG. 6—100X. LINE DRAWING SUPERIMPOSING FIGS. 3 AND 4. (REDUCED ABOUT ½ IN REPRODUCTION.)

boundaries and the temper carbon without having the martensite obscure much of the structure. The superposition was made by projecting the pictures on the drawing board by a lantern and accurately tracing the patterns. It is quite exact, but the need of repolishing a surface after completion of graphitization, even when protected from oxidation, has, of course, exposed a slightly different plane to observation. This accounts, for instance, for the fact that ferrite is occasionally superimposed on temper carbon.

17. We think we see evidence in Fig. 6 that the original

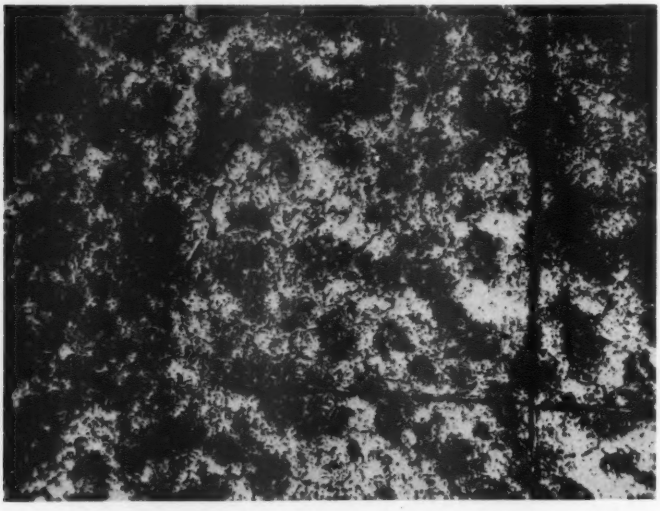


FIG. 7—35X. PHOTOGRAPHIC SUPERPOSITION OF A NEGATIVE OF FIG. 3 UPON FIG. 5, RIGHT AND LEFT REVERSED IN THE PHOTOGRAPHIC PROCESS.

ferrite meshwork encloses areas which finally break up into many ferrite grains. These areas in which there was little ferrite mesh pattern are apparently prone to become relatively large ferrite grains and vice versa. The authors have already (*loc cit.*) pointed to a relationship of ferrite grain pattern to cementite in the as cast metal. None of the ferrite meshwork seems to persist as discrete ferrite grains in the final structure. We find it difficult to account for the observation that the first formed meshwork should represent finally a grain boundary. Perhaps it is *one side* of a ferrite vein which becomes the boundary.

18. In Fig. 7 we have superimposed photographically a re-

versed or negative image of the ferrite nets upon the completely annealed and picrate etched section. The ferrite net, now *black* lines, seem to intersect freely grains of ferrite whether they etched deeply or lightly with alkaline picrate. The individual meshes of the network may enclose areas finally etching both dark and light in the graphitized material or the net may separate dark from light. It appears, therefore, that the network is not conditioned by the original freezing pattern so far as this investigation has shown.

19. The manner of growth of bull's eyes is also of much interest. Bull's eyes may, and frequently do, have but a single layer of ferrite grains, all of approximately similar dimension radially, arranged around the graphite, like flower petals, or occasionally there are several concentric rings of grains surrounding a given temper carbon nodule. Of course, when a sufficient number of such rings exist, they merge into one another leaving few pearlitic (or solid solution as the case may be) areas so small that no particular form of distribution can be traced.

20. Hard iron specimens were held to equilibrium at 925° C. (1695° F.) and then held for various times at various temperatures near the critical point between 770° C. (1425° F.) and 730° C. (1340° F.) with the results shown in Table 1.

21. It appears that, so far as observed, ferrite first appears

Table 1

RESULTS OBTAINED FROM HARD IRON SPECIMENS HELD TO EQUILIBRIUM AT 925° C. (1695° F.) AND HELD AT VARIOUS TEMPERATURES NEAR THE CRITICAL POINT.

Temp. °C.	Temp. °F.	Time hrs.	Amount	Bull's eyes	Network	Pearlite	Solid Solution
770	1418	6	none				
760	1400	5	trace	*	*	none	practically all.
755	1391	5	a little	*	beginning	none	practically all.
755	1391	20	more		well marked	none	mostly
750	1382	5	5%±	present	present	none	95%
740	1364	1/3	trace	*	*	none	nearly all
740	1364	4	20%±	single layer	strong	none	80%±
740	1364	20	80%±	over developed	?	none	20%±
730	1346	5	90%±	merged		present	present

* Ferrite as very small grains at temper carbon nodules.

as very small points adjacent to temper carbon nodules. At and above 755° C. (1391° F.), it then develops principally as a network while at and below 750° C. (1382° F.), it develops both a network and bull's eyes which begin as single layers and later become multilayered and finally over develop into forms not clearly definable.

22. The greater completeness of the reaction in 5 hours at 730° C. (1346° F.) as compared with 20 hours at 740° C. (1364° F.) must not be given too much weight for the original hard iron was not the same. We also note the fact that ferrite does not appear at (or above) 770° C. (1418° F.), *i. e.* that no part of the alloy is below A_1 stable at this temperature, and that some parts of the mass are above their own A_1 metastable point down to 730° C. (1346° F.), none being below their own A_1 metastable point at 740° C. (1364° F.). We can not say how far down A_1 stable extends locally. It is of course, presumably always above A_1 metastable *at the same point.*

23. The effect of various cooling rates through the critical range on the ferrite arrangement is exemplified in the following experiments. The metal was brought to equilibrium at about 925° C. (1697° F.) as before, in a tube furnace in a nitrogen atmosphere, quickly pushed into the hump furnace which was at 900° C. (1650° F.) cooled with that furnace at 770° C. (1418° F.) which might take about one hour or so and then cooled (under automatic control if a rate is indicated) with the furnace completely through the transformation range.

24. Table 2 records data with regard to the metallic matrix.

Table 2

EFFECT OF VARIOUS COOLING RATES ON STRUCTURE

	Ferrite		
Cooling Rate	Amount	Bull's Eye	Network
Oil quenched	none		
Air cooled	trace	*	*
In sil-o-cel	present	†	none
90° F/hr.	50%±	multilayer	present
60° F/hr.	50%±	multilayer	present
30° F/hr.	60%±	multilayer	present
20° F/hr.	80%±	over developed	remnants

* Points at temper carbon.

† As a narrow nearly continuous ring around temper carbon.

25. We note no ferrite network unless cooling is as slow as 90° F. per hr. We note that ferrite comes out most easily adjacent to temper carbon and that bull's eyes perhaps begin as a very narrow band around temper carbon increasing in thickness, then becoming multilayered and finally merging and losing their identity, all this in the order of slower and slower anneal. We have not shown that a given single layered bull's eye can increase in width and later become multilayered.

26. The experiment was repeated on the same metal with the modification that specimens were removed during cooling at about 10° C. (18° F.) intervals and examined. Results are tabulated in Table 3.

Table 3

EFFECT OF COOLING RATE ON STRUCTURE

Cooling Rate	Temp. °C.	Temp. °F.	Ferrite			
			Amount	Bull's Eye	Network	Pearlite
90° F/hr.	740	1364	trace	*	*	none
	730	1346	trace	*	*	none
	720	1328	10%±	single layer.	a little	none
	710	1310	50%±	single and multiple layer.	present	a little
	700	1292	50%±	single and multiple layer.	present.	all
60° F/hr.	750	1382	none			none
	740	1364	trace	*	*	none
	730	1346	trace	*	beginning.	none
	720	1328	10%±	single layer.	a little.	none
	710	1310	50%±	single and multiple layer.	present.	a little
30° F/hr.	750	1382	none			none
	740	1364	trace	*	*	none
	730	1346	2%±	very thin, single. layered.	present.	none
	720	1328	30%±	single layered mostly.	present.	none
	710	1310	60%±	multiple.	present.	all but traces of solid sol.

* Fine points at and near temper carbon nodules.

27. We see that, regardless of cooling rate, (in the range 90° F. per hr. to 30° F. per hr.) ferrite first appears in such metal at a temperature of about 740° C. (1364° F.) and always first near temper carbon. These areas then have an A_1 stable

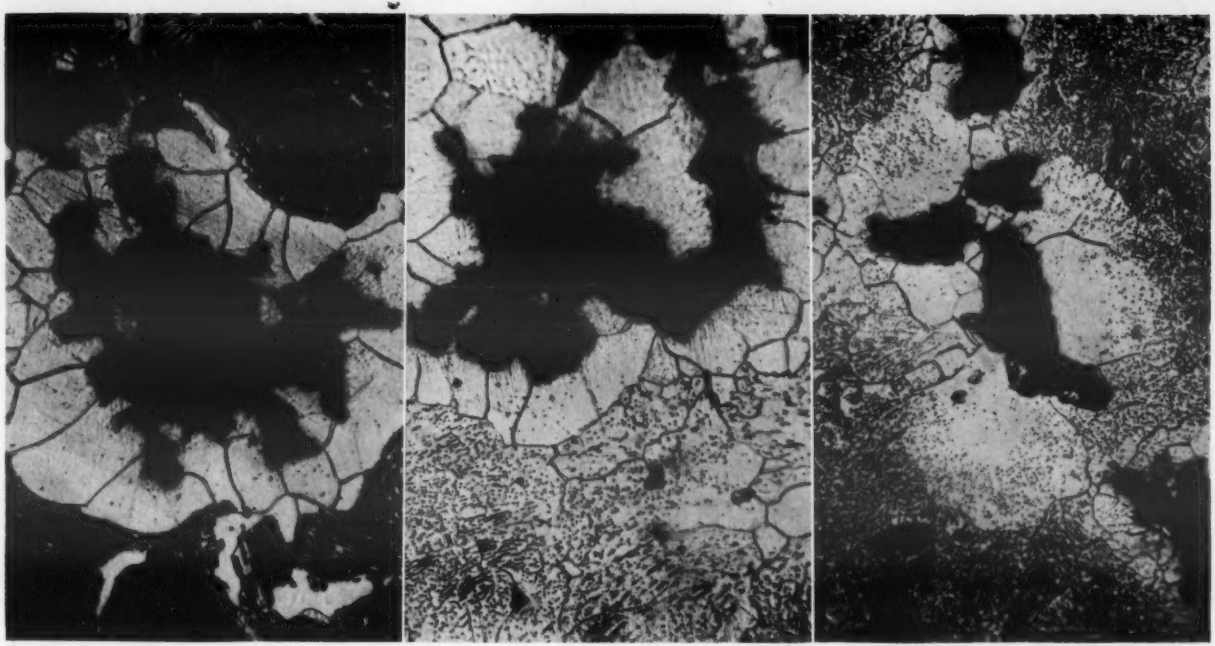


FIG. 8 (LEFT)—500X, ETCHED IN NITAL. TYPICAL FERRITE BULL'S-EYE PRODUCED IN WHITE CAST IRON AFTER COMPLETE GRAPHITIZATION ABOVE THE CRITICAL AND MODERATELY RAPID COOLING THROUGH THE CRITICAL RANGE. COMPOSITION AND EXACT HEAT TREATMENT NOT RECORDED. FIG. 9 (CENTER)—500X, ETCHED IN NITAL. BULL'S-EYE SIMILAR TO FIG. 8 BUT SUBSEQUENTLY HELD 12 HOURS AT 715° C. (1320° F.). FIG. 10 (RIGHT)—500X, ETCHED IN NITAL. WHITE CAST IRON GRAPHITIZED TO EQUILIBRIUM AT 950° C. (1740° F.), COOLED TO 700° C. (1290° F.) IN 15 MINUTES AND HELD ABOUT 3 HOURS AT ABOUT 700° C.

point not lower than 740° C. Pearlite first appears at 710° C. (1310° F.) and the amount at that temperature, in relation to the amount of quenched solid solution, is visibly greater for a cooling rate of 30° F. per hr. than for higher rates. The A_1 metastable point for those areas where this point is at a maximum is therefore a little above 710° C.

28. In Table 1, we noted some appearance of pearlite at 730° C. (1346° F.) in a readily graphitizing metal, but none above. In that table, we note also that, at 740° C. (1364° F.) (in 20 hours), there remains some 20 per cent of undecomposed solid solution but no pearlite. It may be that graphitization is not yet to equilibrium and that ultimately all this solid solution would decompose to ferrite and carbon. In any event, we have clear evidence of graphitization to ferrite in some parts of a metal (i. e. of temperatures below A_1 stable, at least locally) at a temperature above at least A_1 metastable for other localities. If the graphitization is complete in 20 hours, then some areas are still above A_1 stable, but we can not be certain that this is true. There is also some evidence throughout that network ferrite begins to form at temperatures higher than the highest where bull's eyes appear.

29. The data of Table 3 also point to the growth of bull's eyes, first by an increase in the radial dimension of the ferrite crystallites surrounding the temper carbon, and then by the formation of additional concentric rings. Throughout, we never find a grain which is partially ferrite and partially spheroidized. Any given grain seems to be either free from carbon (*i. e.* below the small solubility in ferrite) or of a uniform and fairly high (eutectoid) carbon content throughout.

30. The temperatures here listed are those recorded in the hump furnace. Although they are more precise than commercial furnace operation, they have not the precision required for good critical point work and should be interpreted accordingly.

31. The type of bull's eye so far discussed and better illustrated in Fig. 8, is found only on slow cooling and is characterized by the fact that the grains surrounding the bull's eyes are completely ferritic. Further holding below A_1, results mainly in spheroidizing the pearlitic lamina as shown in Fig. 9. If the critical range be traversed so rapidly as to prevent the growth of the bull's eye and the specimen is then held below A_1 (stable), ferrite will also tend to surround the temper carbon but the grains

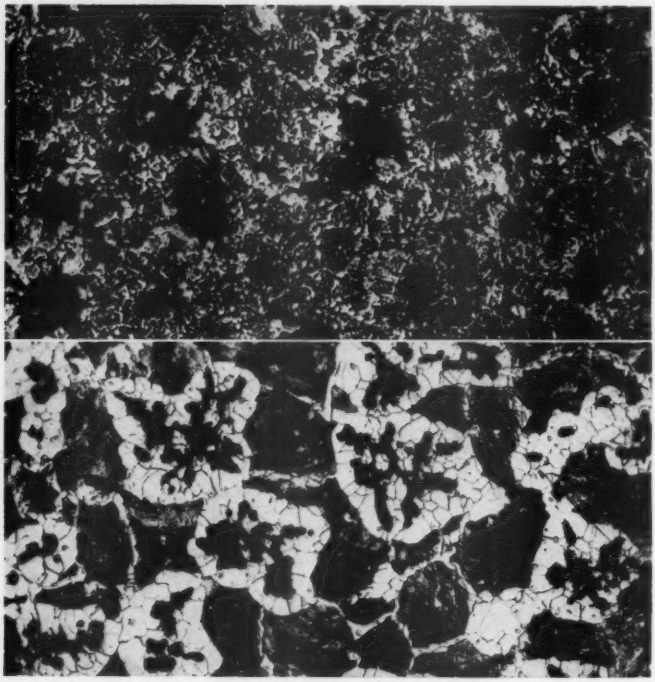


FIG. 11 (ABOVE)—100X, ETCHED IN NITAL. MALLEABLE CAST IRON REHEATED TO 900° C. (1650° F.) SUFFICIENTLY LONG TO ACQUIRE A UNIFORM TEMPERATURE AND COOLED THROUGH THE CRITICAL RANGE AT A RATE SIMILAR TO FIG. 12. FIG. 12 (BELOW)—100X, ETCHED IN NITAL. MALLEABLE CAST IRON HEATED TO 925° C. (1695° F.) FOR 50 HOURS AND COOLED AT 22° C. (39.6° F.) PER HOUR THROUGH THE CRITICAL RANGE.

surrounding the carbon are then ferritic adjacent to the graphite but contain spheroidized cementite, resulting from partial destruction and complete spheroidization of pearlite lamina at a distance from the graphite. This condition is shown in Fig. 10. There is thus an agraphitic carbon gradient in a single grain in contradistinction to the absence of such a gradient in the preceding figure.

32. Another peculiarity of the bull's eye structure is that, while it forms readily during cooling after the first stage of graphitization, it in general does not develop in malleable iron which has been reheated to well above its A_{c_1} point for a time which has *apparently* sufficed to resaturate the matrix with carbon. Fig. 11 shows the rather confused and random separation of ferrite resulting on subsequent cooling. If, however, the metal be held

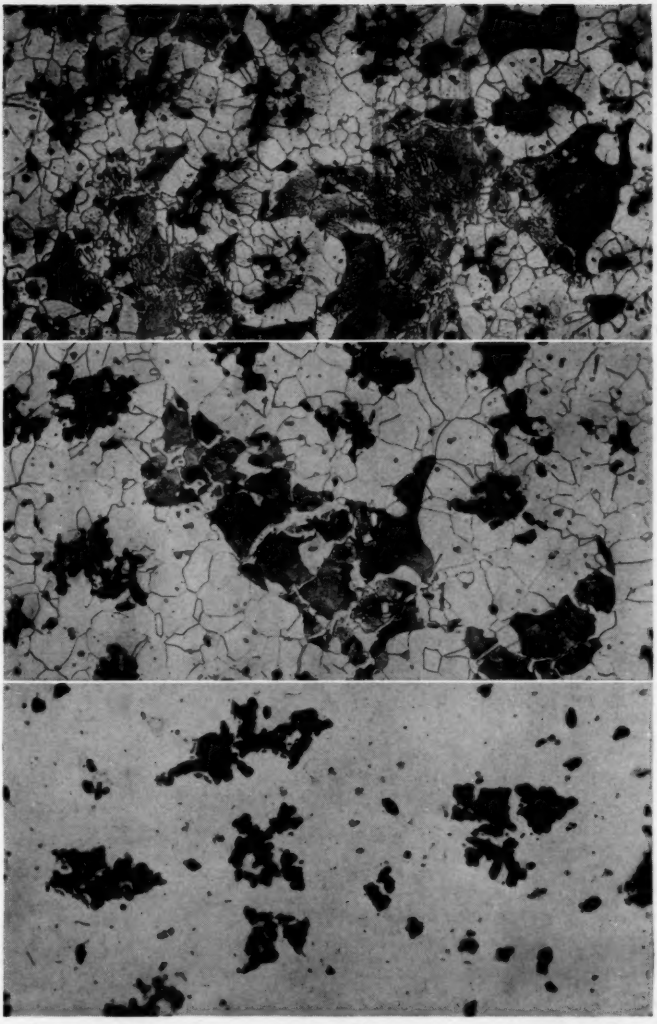


FIG. 13 (TOP)—100X, ETCHED IN NITAL. WHITE CAST IRON GRAPHITIZED TO EQUILIBRIUM IN DRY NITROGEN AT 925° C. (1695° F.), COOLED TO 770° C. (1420° F.) IN 4 OR 5 MINUTES AND SUBSEQUENTLY TO BELOW THE CRITICAL POINT AT 11° C. (19.8° F.) PER HOUR. FIG. 14 (CENTER)—100X, ETCHED IN NITAL. WHITE CAST IRON IDENTICAL WITH THAT USED IN FIG. 13 HEATED IN DRY NITROGEN TO COMPLETION OF GRAPHITIZATION AT 925° C. (1695° F.) COOLED IN 1 HOUR TO 770° C. (1420° F.) AND SUBSEQUENTLY AT 11° C. (19.8° F.) PER HOUR TO BELOW THE A_1 POINT. FIG. 15 (BELOW)—100X, UNETCHED. WHITE CAST IRON IDENTICAL WITH FIGS. 13 AND 14 GRAPHITIZED IN DRY NITROGEN TO COMPLETION AT 925° C. (1695° F.) COOLED IN 4 OR 5 MINUTES TO 770° C. (1420° F.) AND SUBSEQUENTLY TO BELOW THE CRITICAL AT 28° C. (50.4° F.) PER HOUR.

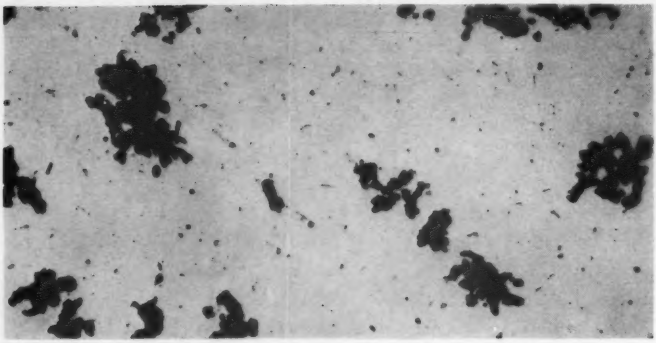


FIG. 16—100x, UNETCHED. IDENTICAL WITH FIG. 15 EXCEPT THAT COOLING FROM 925° C. (1695° F.) TO 770° C. (1420° F.) OCCUPIED 1 HOUR.

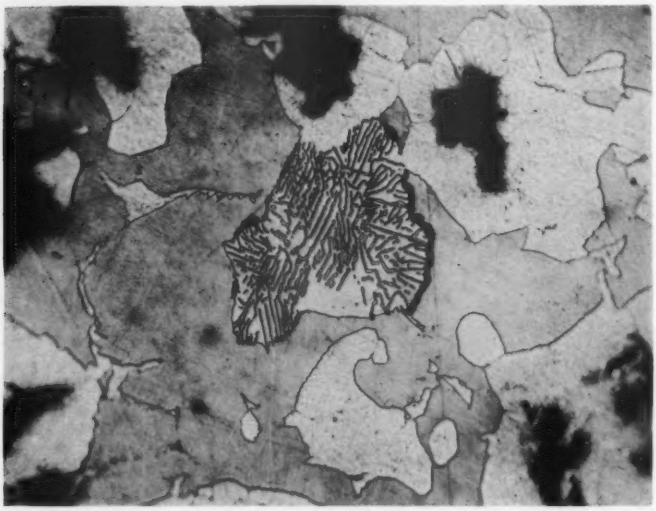


FIG. 17—500x, ETCHED IN NITAL. WHITE CAST IRON DESCRIBED UNDER FIG. 1, HEATED TO EQUILIBRIUM IN DRY NITROGEN IN 4 HOURS AT 975° C. (1785° F.) AND SUBSEQUENTLY FOR 1 HOUR AT A TEMPERATURE APPROXIMATING 710° C. (1310° F.).

above A_{c_1} for some time, perfectly developed bull's eyes will be formed as shown in Fig. 12. It appears that this phenomenon may be related to the tenacious persistence of minute ferrite crystallites at a temperature which probably is not above the A_{c_3} point of carbon free metal of this silicon content.

33. Although the temperatures at which ferrite veins and

bull's eyes appear seem not to be greatly affected by cooling rates at higher temperatures than the maximum A_{r_1} stable, yet the ferrite grain size is greatly affected as is also the fineness of pearlite lamination. Figs. 13 and 14 show that with a given cooling rate through A_1 a cooling rate of 155° C. per hr. (280° F. per hr.) above 770° C. (1420° F.) produces a much coarser ferrite structure and a much finer pearlite than a cooling rate twelve times as fast in the same range. It is of incidental interest that, as shown in Figs. 15 and 16, the faster cool above A_1 results in the formation of temper carbon nodules of two distinct orders of magnitude while with the slower cool, although small nodules exist, they have not grown to appreciable magnitude.

34. The extremely coarse pearlite-like aggregate, shown in Fig. 17, is typical of what can often be seen in certain incompletely annealed types of malleable iron. Its existence, almost completely surrounded by what appears to be a homogeneous quenched solid solution (probably austenite) and the apparently troostitic band intervening between it and the solid solution, seems to identify it as probably a decomposition product of austenite which has formed at a temperature where some areas were below A_{r_1} stable, some below A_{r_1} metastable, and some above A_{r_1} metastable and perhaps also above A_{r_1} stable.

35. We have attempted in this paper to describe what goes on at various stages of a well known process. The great speed of completion of graphitization in a range probably defined as that between the A_1 stable and metastable points, may not have been actually known to all practitioners of the art of annealing but has been used "since the memory of man runneth not to the contrary" in the form of a slow cool through a rather long critical temperature range which resulted, unconsciously, in the early years at least, in spending a considerable time in this range. If this range were not so narrow, if it did not vary considerably with silicon content and perhaps even due to segregation and if it were possible to hold every casting of a charge within a very few degrees of a predetermined temperature, second stage annealing might be shortened by eliminating slow cooling through unimportant temperature ranges.

36. Pending such improvements in furnace engineering as would make this possible, the ancient expedient of a rather slow cool through so long a range as will give every casting and every part of each sufficient time at all useful temperatures to empirically

produce the desired result, will probably continue in use. Economically this does not involve any great handicap for slow cooling in a well insulated furnace is not a very expensive process involving no consumption of labor and little or none of fuel.

37. Despite the fact that we are not teaching the malleable founder new tricks, we hope that a study of the metallographic changes occurring during cooling in annealing may be of some interest as showing the sequence of changes in an old and well established process.

DISCUSSION

W. R. BEAN[1]: There are two or three different aspects of what has been shown that are extremely interesting to me, because they explain certain things that we have seen, have recorded, and have published in a paper that was presented[2] to the A.F.A., covering work done over a number of years prior to 1920.

One in particular relates to a micrograph which we showed of a very small casting, a casting 5/8-in. in its extreme dimension, where there was a variation from practically complete graphitization to definitely incomplete graphitization. It had not seemed possible to us that the transition there could be so delicate as to provide those two conditions, but what has been shown in the different micrographs from a section only 6-in. long proves quite conclusively that the change is one that is very delicate, and that it is possible to catch widely varying structures over very small areas.

The bull's eye structure was probably first recorded in the work that was done by my associates and myself prior to 1920. That term was just a haphazard designation by us of a condition that we saw. The structure came on to the screen when we were examining a specimen, and we labeled it "bull's eye." It is interesting that this term is now fairly definitely established in the metallurgy and metallography of malleable iron.

We did not then, and I have not since, studied cooling rates as critically and as exhaustively as Dr. Schwartz has done. Certain conditions are developed which may prove to be valuable in connection with the tendency which now exists, to make different types or different kinds of malleable through the process of heat treatment starting with substantially the same base that we have always had. The record is one that should prove very valuable to metallurgists, and is a distinct contribution to the data on malleable production, annealing, and graphitization.

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[1] Vice-President, Whiting Corp., Harvey, Ill.

[2] Bean, W. R., Highriter, H. W., and Davenport, E. S., *"Fractures and Microstructures of American Malleable Cast Iron,"* TRANS. A.F.A., vol. 29, pp. 306-340.

D. P. FORBES[3]: I think this paper is extremely interesting, particularly showing as it does the different results obtained by using a temperature gradient, in the temperature range of second stage annealing. This clarifies many phenomena which we have observed and did not completely understand. One point that is particularly important is that if accuracy of heat treatment could be maintained both in the rate of cooling from the high temperature and in the temperature of holding, it should be possible to accelerate the anneal enormously. That, it seems to me, offers much promise, particularly on continuous furnaces of some kind which could actually maintain temperatures quite closely.

[3] President, Gunite Foundries Corp., Rockford, Ill.

Notes on Fatigue Properties of Cast Iron

By HARRY L. DAASCH*, AMES, IOWA

Abstract

The paper reports data of fatigue tests on two high strength alloy cast irons, secured in an investigation to determine the endurance limit, endurance ratio, and the effect of notches on the endurance limit. Each cast iron was alloyed with nickel, molybdenum and chromium, one iron giving a tensile strength of about 57,000 lb. per sq. in., and the second about 44,000 lb. per sq. in. The endurance ratios of the two irons were found to be .41, with the endurance limits being 18,000 and 24,000 lb. per sq. in. The findings of other investigators are discussed and their results compared with those of the present paper. The author stresses the desirability of those designing, when using higher strength cast metals, recognizing the importance of stress raising notches.

1. The importance of cast alloy irons in present and future machine design and construction is well illustrated in the automotive industry. A few years ago no engineer would have considered the use of cast crankshafts in any internal combustion engine. In 1925, a prominent engineer[1]† wrote in a book on engine design, "Steel is the only known material that possesses sufficient strength, rigidity, and reliability to be satisfactorily employed for engine crankshafts." Within the short period of less than a decade, metallurgical research and development have established the practicability of cast crankshafts; design procedures have followed the lead; and, during the past several years, the regular production of cast alloy camshafts and crankshafts has become a reality.

2. The extent of these new practices is indicated by current production where over one-fourth of the automobile engines utilize cast camshafts, while another 25 per cent or more of the same total output are equipped with cast crankshafts. The im-

* Associate Professor, Mechanical Engineering, Iowa State College.
† Superior numbers refer to bibliography at the end of the paper.

petus given to the use of cast metals and the influence on machine design practices may be forecast in terms of these specific applications.

3. These phenomenal changes may be considered all the more startling when the lack, in published form, of physical property data is considered. E. A. Piper[2] has emphasized the fact that even recent issues of engineering handbooks do not contain information pertaining to present day cast irons. Statements propounding fatigue strength advantages of the modern cast irons have appeared recently in the technical press. These statements are generally made unaccompanied by fatigue strength values. Specific facts and figures would appear of greater value than broad and generalized assertions. This paper is a report of certain fatigue tests. The purpose of the tests was to determine the endurance limit, the endurance ratio, and the effect of notches on the endurance limit of two high strength alloys. A review and correlation of published information is offered.

MATERIALS TESTED

4. Two different cast irons, produced in the form of simple cylindrical cast sections, were used in these tests. These metals were electric furnace products. Metal *A* was initially cast in 2¾ inch diameter by 15 inch long specimens, and metal *B* was produced as 1¼ inch diameter sections. The analysis of metal *A* was: 2.52 per cent carbon, 2.44 per cent silicon, 0.56 per cent manganese, 2.14 per cent nickel, 0.17 per cent chromium, and 0.95 per cent molybdenum. Metal *B* was somewhat lower in alloy content; the analysis was: 3.34 per cent carbon, 2.63 per cent silicon, 0.66 per cent manganese, 0.56 per cent nickel, 0.37 per cent chromium, and 0.52 per cent molybdenum. Both metals showed a characteristic pearlitic matrix. Micrographs are shown as Fig. 10.

EQUIPMENT AND TESTS

5. A battery of six fatigue testing machines, set up as shown in Fig. 1, was used. These units were belt driven from a motor beneath the table and operated at a normal speed of 1500 R.P.M.

6. The machines, which were of the Farmer type, did not differ materially from the conventional equipment of this kind. In effect, the test bar was a part of a rotating beam supported on free moving ends and loaded at the third points. Due caution was taken to insure proper alignment of test bars and to eliminate

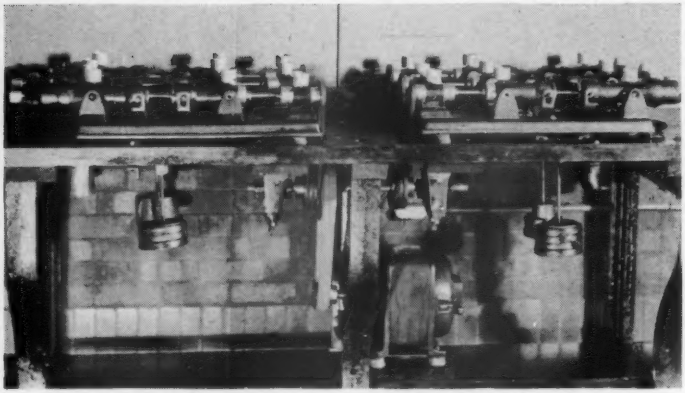

FIG 1—BATTERY OF SIX, FARMER-TYPE, FATIGUE TESTING MACHINES.

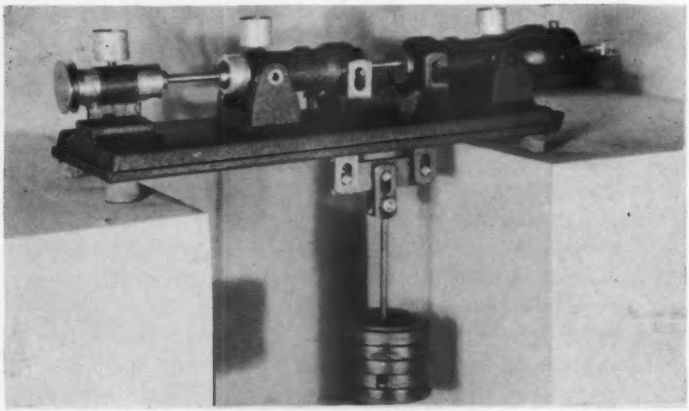

FIG. 2—CLOSE-UP OF ONE OF THE FATIGUE TESTING MACHINES SHOWN IN BATTERY LAYOUT OF FIG. 1.

vibration as much as possible. To this end, ruggedness in design and rubber mounting of motor, countershaft and machines were adopted. Similarly, plain babbitted bearings were adopted as superior to ball bearings from the viewpoint of vibrations. Fig. 2 is a closeup view of one of the machines.

7. Several types of test bars were used. All were 0.300-in. in diameter. The usual long radius type, as well as two styles of short radius and sharp notch bars, were tested. Details of these bars are shown in Fig. 3. The test bar shown as 3a will hereafter

be referred to as the 9.85-in. radius bar. Similarly, 3b and 3c will be known as the 1/8-in. radius notch and V-notch test bars respectively. The bars were carefully polished with jewelers rouge after grinding to dimension.

8. The usual procedures in conducting tests of this kind were followed. Orthodox *S-N* diagrams with characteristic "knee" type curves were plotted on semi-logarithmic coordinates.

TEST DATA AND RESULTS

9. The fatigue strength or endurance limit, as it is generally called, may be defined as the limiting stress below which metals will withstand without fracture an indefinitely large number of

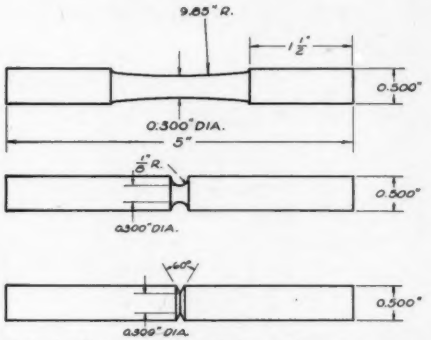

FIG. 3—FORM OF BARS USED IN FATIGUE TEST.

reversals of stress. This value is shown as the stress at which the *S-N* curve assumes a horizontal position.

10. In some tests, a scatter of points on the curve diagrams may be interpreted as showing a lack of uniformity in these materials. In many cases, early or irregular test failure could be accounted for by visible defects at the point of failure.

11. In addition to the fatigue tests, tensile and compressive strengths as well as Brinell hardness values were determined. On the basis of test values, the endurance ratio was determined. The endurance ratio has been generally expressed as the ratio of fatigue strength to ultimate tensile strength.

12. Fatigue test data pertaining to Metal *A* are shown in Tables 1 and 2. Two series of tests incorporating the long radius and the ⅛-in. notch are indicated.

13. The results of these two series of tests are shown in

Table 1

METAL "A"

0.300 Inch Diameter Test Bars
(9.85-In. Radius)

Test No.	Bar No.	Cycles	Calculated Stress, lb. per sq. in.
1	4	3,600	46,400
2	5	43,400	43,400
3	6	56,900	38,200
4	3	93,000	33,800
5	2	138,800	28,800
6	1	1,290,000	25,800
7	9	16,750,000*	27,200
8	7	24,800,000*	21,600
9	8	48,600,000*	23,600

* Specimen did not fail.

Table 2

METAL "A"

0.300 Inch Test Bars
(⅛-In. Radius Notch)

Test No.	Bar No.	Cycles	Calculated Stress, lb. per sq. in.
1	5	125	29,800
2	2	10,750	29,950
3	4	11,520	38,100
4	6	13,820	29,800
5	3	36,850	34,100
6	9	230,400	29,800
7	1	616,000	25,500
8	7	25,200,000	23,880
9	8	42,250,000*	22,180

* Specimen did not fail.

Table 3

PHYSICAL PROPERTIES METAL "A"

Endurance Limit, lb. per sq. in.	
(9.85-In. Radius Test Bar)	23,600
(⅛-In. Radius Notch Test Bar)	22,180
Tensile Strength, lb. per sq. in.	57,100
Compressive Strength, lb. per sq. in.	144,130
Brinell Hardness	275
Endurance Ratio	
(9.85-In. Radius Test Bar Basis)	0.41

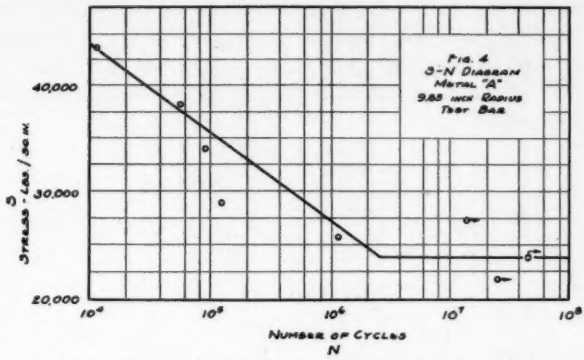

FIG. 4—S-N DIAGRAM METAL "*A*," TEST BAR 9.85-IN. RADIUS.

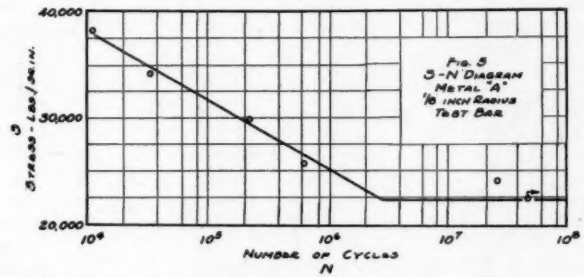

FIG. 5—S-N DIAGRAM METAL "*A*," TEST BAR 1/8-IN. RADIUS.

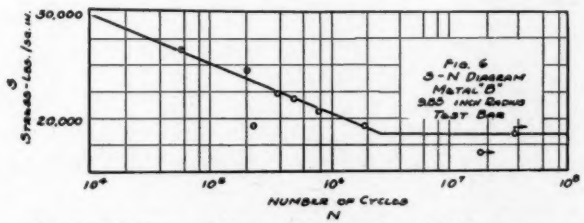

FIG. 6—S-N DIAGRAM METAL "*B*," TEST BAR 9.85-IN. RADIUS.

graphical form by Figs. 4 and 5 respectively. The characteristic stress-cycle curves are shown, and the reduction in the endurance limit of this metal due to the notch is evident.

14. The physical properties of Metal *A* have been tabulated in Table 3.

15. The results of fatigue tests of Metal *B* are shown in

tabular form in Tables 4, 5, and 6. Figs. 6, 7, and 8 show these same data in graphical form. Table 7 is offered as a summary of physical test results for this metal. Fig. 9 has been drawn as a composite of previous S-N diagrams. Comparative values are self evident.

DISCUSSION

17. The test results reported here should be considered on the basis of: (1) Specific endurance limit values, (2) Endurance ratios, (3) Effect of notches.

Table 4

METAL "B"

0.300 Inch Diameter Test Bars
(9.85-In. Radius)

Test No.	Bar No.	Cycles	Calculated Stress, lb. per sq. in.
1	3	4,603	21,500
2	9	59,400	26,350
3	8	171,500	23,100
4	11	206,000	24,500
5	5	228,000	19,200
6	10	354,000	22,250
7	1	448,000	21,600
8	2	794,000	20,600
9	6	1,910,000	19,200
10	7	10,800,000	16,500
11	4	22,870,000*	18,200

* Specimen did not fail.

Table 5

METAL "B"

0.300 Inch Diameter Test Bar
(⅛-In. Radius Notch)

Test No.	Bar No.	Cycles	Calculated Stress, lb. per sq. in.
1	6	14,100	23,700
2	1	92,200	20,360
3	8	134,000	22,050
4	7	149,000	22,050
5	4	503,000	17,820
6	9	365,000	18,660
7	5	6,170,000	16,960
8	2	12,250,000	16,550
9	3	40,050,000*	15,280

* Specimen did not fail.

Table 6

METAL "B"

0.300-In. Diameter Test Bar
(60 Degree V-Notch)

Test No.	Bar No.	Cycles	Calculated Stress, lb. per sq. in.
1	2	332,000	17,820
2	7	473,000	18,770
3	6	818,000	15,280
4	4	868,000	14,430
5	3	960,000	15,280
6	1	1,018,000	16,120
7	5	33,660,000*	13,570

* Specimen did not fail.

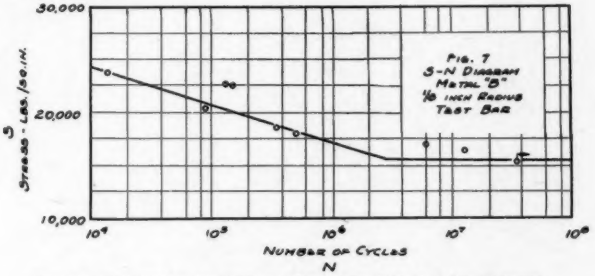

FIG. 7—S-N DIAGRAM METAL *"B,"* TEST BAR 1/8-IN. RADIUS.

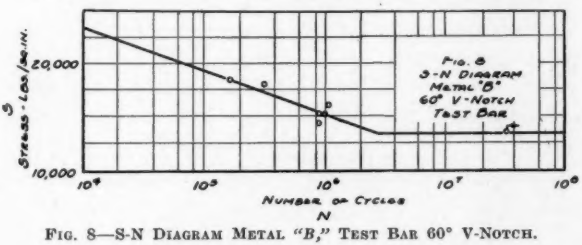

FIG. 8—S-N DIAGRAM METAL *"B,"* TEST BAR 60° V-NOTCH.

Table 7

PHYSICAL PROPERTIES METAL "B"

Endurance Limit, lb. per sq. in.	
(9.85-In. Radius Test Bar)	18,200
(⅛-In. Radius Notch Test Bar)	15,280
(60° V-Notched Test Bars)	13,570
Tensile Strength, lb. per sq. in.	44,130
Compressive Strength, lb. per sq. in.	139,000
Brinell Hardness	261
Endurance Ratio	
(9.85 Inch Rod Test Bar Basis)	0.41

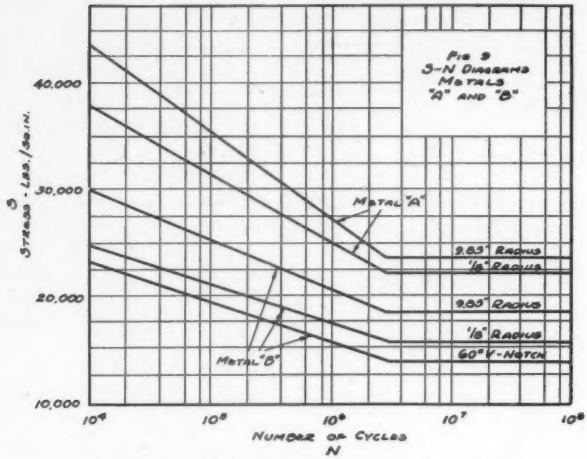

FIG. 9—S-N DIAGRAM FOR METALS "*A*" AND "*B*."

Table 8

VALUES FOR ENDURANCE RATIO OF CAST IRON AS DETERMINED BY VARIOUS INVESTIGATORS

	Endurance Ratio
Metal "*A*" Alloy Iron	
Iowa State College Tests	0.41
Metal "*B*" Alloy Iron	
Iowa State College Tests	0.41
Gray Cast Iron	
Thum and Ude[4]	0.35 to 0.45; Ave., 0.40
University of Wisconsin Tests[5]	0.38 to 0.57; Ave., 0.49
University of Illinois Tests[6]	0.33 to 0.46; Ave., 0.37
Cast Steel	
University of Illinois Tests[7]	0.40 to 0.46; Ave., 0.43
Timoshenko and Lessells[8]	0.40 to 0.44; Ave., 0.42
Cast Alloy Steel	
Strauss[9]	0.477 and 0.482
Timoshenko and Lessells[8]	0.47 to 0.52; Ave., 0.49

Specific Endurance Limit

18. The endurance limits for the two alloy cast irons were approximately 18,000 and 24,000 lb. per sq. in. These values are quite similar to those determined by Moore and Picco[3] on high test cast irons which were cast in comparable size sections.

Endurance Ratio

19. The endurance ratios of the metals studied in these tests were 0.41. These values may be compared with those reported for other metals. The figure usually accepted for rolled, forged or heat treated steels is about 0.50.

20. Table 8 shows values obtained by various investigators and reported by them for various cast ferrous metals.

21. The endurance ratios obtained in this investigation for the cast alloy irons and the values previously reported by other investigators for cast steels and cast irons are of the same general magnitude. However, certain details and characteristics may be worthy of further discussion.

22. The value of 0.49 reported by Kommers of the University of Wisconsin should be noted. This value was claimed because of the special precautions to prevent vibrations in the test machine and specimens. The relative degree of vibration elimination in the tests reported here as compared to the setup used by Kommers is, of course, unknown. However, with the precautions already described, very smooth operation was secured in the tests conducted by the present author. The endurance ratio of 0.41 was obtained.

23. The University of Illinois tests, showing a variation of endurance limits from 0.33 to 0.46 and with an average value of 0.37, were conducted on several different kinds of gray iron. It is significant that the high value of 0.46 pertains to the highest Brinell hardness iron (Brinell number 160). This iron contained the highest percentage of combined carbon. Although not conclusive, there seems to be a tendency toward lower endurance ratios for the softer and high graphitic irons in this group of tests.

24. The values of endurance ratios on cast steels is included as a matter of comparison. The value of 0.482, reported by Strauss, was on a cast nickel-vanadium steel. Physical tests on coupon bars yielded a tensile strength of 91,450 lb. per sq. in. and the quoted endurance ratio of 0.482. Strauss also reported an endurance ratio of 0.477 on a manganese-vanadium cast steel of 109,100 lb. per sq. in. tensile strength. It may be noted further that Strauss recognizes and suggests a rather unusual and high combination of physical properties. The data quoted from Timoshenko and Lessells have been secured on three cast steels including a low carbon, a medium carbon, and an alloy. It is interesting that the endurance

ratios were: for low carbon 0.43 and 0.42; for high carbon 0.40, 0.44, and 0.41; and for the alloy cast steel 0.48, 0.52, and 0.47.

25. The foregoing review suggests that the endurance ratios of cast steels may be expected to be greater than those of cast irons. Further, the values for high strength cast irons may be somewhat greater than those of soft or weak gray irons. These general statements are susceptible to further check.

Effect of Notches

26. The deleterious effect upon fatigue strength of notches and even scratches or tool marks has been established by previous researches. The tests here reported involving 1/8 in. radius and sharp 60 degree notches, were intended to show the susceptibility of these cast alloy irons to these stress raisers. The decrease in fatigue strength caused by notches is indicated by Table 9.

Table 9

INFLUENCE OF NOTCHES ON FATIGUE STRENGTH

	Decrease in Fatigue Stress			
	1/8 in. Rad. Notch		60° Notch	
	Lb. per sq. in.	Per cent	Lb. per sq. in.	Per cent
Metal *A*	1420	6.1	....	....
Metal *B*	2920	16.0	4360	25.4

27. Tests reported by Moore[10] and his associates showed a decrease in the endurance limit of a gray cast iron of zero and 8 per cent when filleted grooves were adopted as stress raisers. Kommers[11] found a slight increase in the endurance limit of a low strength cast iron when a square notch was cut in the specimens. Thum and Ude[12] found little or no effect of stress concentration notches in their tests on cast iron.

28. These results may be compared with those of Brophy[13] who found a reduction of approximately 30 to 35 per cent in the endurance limit of cast iron when a 45° sharp notch was used.

29. Table 9 has already been referred to as showing data secured in the author's laboratories. The metals studied may be classed as high strength cast irons, and graphitic carbon is less than in the regular gray irons studied by the investigators noted in the previous paragraphs.

30. All of the evidence is in support of the postulated theory that graphitic carbon particles act as inherent stress raisers. Although all values are less than those usually accepted for forged,

rolled, or heat treated steels, the correlation with any single item such as graphite is not too clear.

31. There are a large number of other factors which may be involved in a material as heterogeneous as cast iron. The author believes that a great deal of study may still be expended on this point. This is particularly true of the study of notch sensitivity and dampening characteristics.

32. The fact that man-made stress-raising notches and sharp corners are of little significance, must be accepted with more and more reservation as higher quality irons are used in machine parts operating under repeated loads. The desire for higher strength cast metals and the acceptance of the decrease of notch sensitivity in cast metals with graphitic carbon are naturally not compatible.

33. The author feels that greatest advances may be made in the direction of higher strengths and a recognition that man-made stress risers should be avoided by filleting and similar precautions. Very recent practices in the applications of cast metals to repeated and dynamically loaded machine parts seem to be in that direction.

34. It might be said here that design as well as material specification in connection with dynamically loaded machine parts is oftentimes quite empirical. The immediate economic demands of commerce will not always permit of complete investigation and understanding of all details. Nevertheless, the foundry industry may be best advanced, in the long run, by proper and wise application of its products. The zeal and pressure of industry may be satisfied, if slowly, by establishment of truths on questionable items suggested in this paper.

CONCLUSIONS

35. Conclusions reached are:

(1) The endurance limit of two alloy cast irons has been determined as 18,000 and 24,000 lb. per sq. in.

(2) The endurance ratios of these two alloy cast irons have been found to be 0.41.

(3) The use of an endurance ratio of about 0.40 seems reasonable for high strength cast irons with slightly lower values for regular gray irons and higher values for cast steels.

(4) A decrease of from 6 to 16 per cent has been found for a

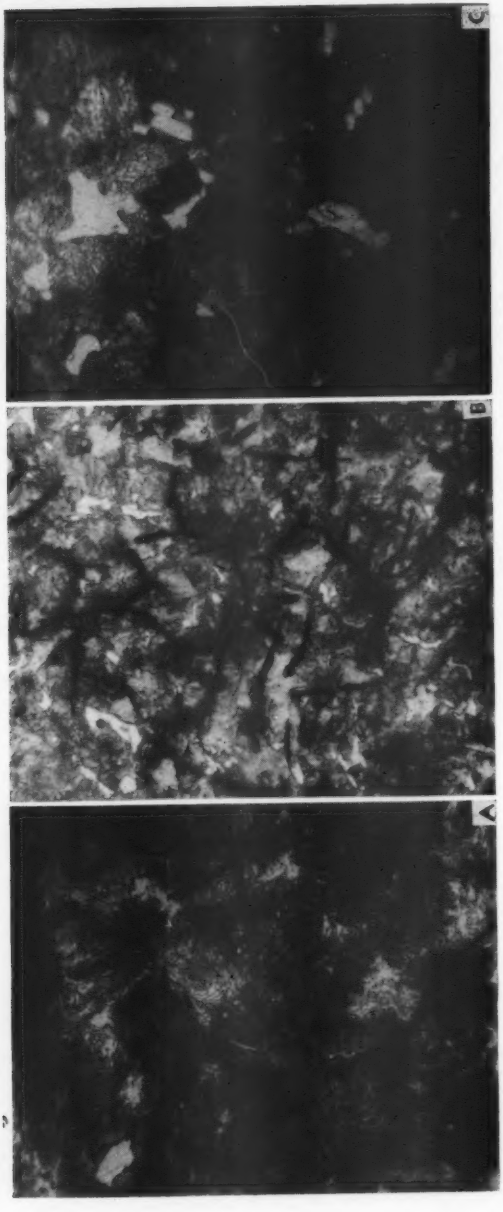

FIG. 10—MICROGRAPHS OF THE TWO IRONS TESTED. (A) METAL A, NITRIC ETCH, 500X. (B) METAL B, NITRIC ETCH, 150X. (C) METAL B, NITRIC ETCH, 500X.

1/8-in. radius filleted test section with a 25 per cent decrease for a 60° V-notch test bar.

(5) Machine design practice leading toward higher strength cast metals should recognize the importance of the elimination of stress raising notches.

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DISCUSSION

In absence of the author, this paper was presented by J. W. Bolton, Lunkenheimer Co., Cincinnati, Ohio.

J. B. KOMMERS[1] (*Submitted in Written Form*): I have read this paper with much interest. I wish to call Professor Daasch's attention to two references on cast iron which he does not list. One is "Impact Testing of Cast Iron," published by a Sub-committee of Committee A-3 on Cast Iron, of the American Society for Testing Materials, in 1933. The other is an article on "Understressing and Notch Sensitiveness," published by the writer in the Engineering News-Record, of Sept. 22, 1932.

The first reference covers probably the most complete series of tests on various cast irons which has ever been published. It includes transverse, tension, fatigue, compression, shear, hardness, and a variety of impact tests on 25 different cast irons, ranging in tensile strength from 16,700 to 56,700 lb. per sq. in. The endurance limits of these cast irons were determined by the writer.

The endurance limit was determined for 24 of these irons, and the endurance ratio varied between 0.43 and 0.63, giving an average ratio of 0.50. The three irons which had tensile strengths close to the values of those reported by Professor Daasch, had tensile strengths of 56,700, 47,230, and 40,920 lb. per sq. in. The corresponding endurance ratios were 0.44, 0.53, and 0.48.

The second reference mentioned above is of interest in connection with the subject of notch-sensitivity of cast iron. The following table, quoted from the article, gives the results of the effect of a sharp square notch on a series of cast irons of increasing tensile strength.

EFFECT OF SQUARE NOTCHES ON ENDURANCE LIMIT

Cast Iron No.	1 Ultimate Tensile Strength lb. per sq. in.	2 Standard Specimen Endurance Limit lb. per sq. in.	3 Notched Specimen Endurance Limit lb. per sq. in.	4 Decrease of Column 3 Compared with Column 2, per cent
1	20,000	9,300	9,300	0
2	23,200	11,800	11,200	5.1
3	30,300	15,000	13,700	8.6
4	37,100	19,500	16,300	16.4
5	42,500	24,100	19,100	20.7

This table shows very plainly that as the tensile strength of the cast iron increases the material becomes more and more sensitive to notches, with the result that the endurance limit is reduced by greater percentages. However, it should be noted that the greatest reduction shown in the table is still considerably less than that which steels would show for a similar notch. Tests on five different steels, made by the writer at the Universi-

[1] Professor of Mechanics, College of Mechanical Engineering, University of Wisconsin, Madison, Wis.

ties of Illinois and Wisconsin, show that such a notch reduces the endurance limit from 37 to 52 per cent.

One comment may be made on the endurance limits reported for Metals *A* and *B* by Professor Daasch. The results shown in Table 1 indicate that the endurance limit of metal *A* may be higher than 23,600 and nearer the value of 25,800 lb. per sq. in. In the same way, Table 4 shows that the endurance limit for metal *B* may be higher than 18,200 and nearer the value of 19,200 lb. per sq. in. If that were the case the endurance ratios would be higher than 0.41.

J. W. BOLTON[2]: In determining the tensile strength and the fatigue limit on this material, Prof. Daasch has not indicated clearly the size test specimen on which the tensile strength was obtained. If the tensile strength were determined on, say, a 0.505 in. diameter bar, or on a 0.80 in. diameter bar, and then the endurance limit were determined on a portion near the heart of that bar, say on a 0.30 in. diameter bar, an erroneous idea of the endurance ratio would be obtained.

CHAIRMAN J. T. MACKENZIE: I might say that these endurance tests have one error that is not commonly recognized. That is they use bending strength and they are based on tensile strength. The ratio of the bending strength to the tensile strength in cast iron varies from about 2.3 down to about 1.8, depending on the strength of the iron. For these particular irons, I should say the bending strength is twice that of the tensile. But there is not that large an error because the departure from the elastic curve is quite small up to about half the load, which is beyond the fatigue limit. Thum figured out the error was of the order of 5 per cent.

Another thing I would like to draw attention to is that Prof. Daasch did not remember our impact report, where Prof. Kommers made some beautiful fatigue tests on 25 cast irons. On those irons, they also have available 0.5 in. diameter bar transverse tests.

The matter of the sharp notch is another thing that is a very moot question. When you say a "V" or a sharp notch, then it becomes a question as to how sharp is it? That is quite important in steel but it does not look as though it would be important in cast iron, since there is a very small drop-off from the $\frac{1}{8}$-in. radius, to what he calls the "sharp V." I think it would be well to ask Prof. Daasch to add to the paper the details of the specimen used and also give us a profile of that notch.

MR. BOLTON: The author gives the endurance ratio for steels without notches but he does not bring the question of the notch in there. For a full comparison, he should submit an illustration of the notch, if he will, on the steel, which in some cases is quite serious. That is not mentioned in this paper.

PROF. DAASCH (*Author's Written Closure*): I wish to thank Mr. Bolton for his kindness in presenting the paper in the author's absence.

The omission of reference to the report of the Sub-committee of Committee A-3 on Cast Iron of the American Society for Testing Materials published in Proceedings of the A.S.T.M., Vol. 33, was accidental. As

[2] Metallurgist, The Lunkenheimer Co., Cincinnati, Ohio.

Professor Kommers has indicated the report covers a great number of various types of tests. It is interesting to note that a number of alloy cast irons (Nos. G, J, K, L, M, S and Z) were found to have endurance ratios of from 0.44 to 0.50 with an average of 0.46. The comparisons offered by the present writer apply to the above tests. Furthermore, close examination of endurance ratios and analysis shows no correlation.

In answer to Mr. Bolton's question, tension tests were made on regular 0.505 x 2 in. test bars.

A word of caution in the use of test data may be offered in the light of remarks by Messrs. Bolton and MacKenzie. Endurance limits and endurance ratios, quoted by the author as well as other investigators in this field, recognize the methods of test. The author wishes to emphasize that interpretation and use of such data in design of machine parts is a still fertile field for study. Exaggerated claims as well as unjust degrading of cast iron products may easily result because of faulty correlation of laboratory test data and commercial application. A purpose of the paper will have been accomplished in the recognition of these facts.

The author wishes to thank Professor Kommers for calling attention to the article on "Understressing and Notch Sensitiveness." The information therein given is in full accord with that presented by the writer in the present paper and emphasizes the greater susceptibility of high strength cast irons to notches. The need of more general fillets in the use of strong irons is therefore indicated.

A.F.A. Grain Distribution Numbers for Foundry Sand

Tentative Standard

Submitted by Sub-Committee on Grading, Foundry Sand Research Committee

This method for determining A.F.A. Grain Distribution Number for foundry sands was prepared by the Sub-Committee on Grading of the Foundry Sand Research Committee, was submitted to the latter committee for review and was approved as a Tentative Standard.

This report will appear in the next edition of the publication "Testing and Grading of Foundry Sands—Standards and Tentative Standards," the last issue of which was published in March 1931.

Foreword.

Past experience has shown that the A.F.A. Grain Fineness Number,[1] when used alone, does not completely define the Grade Test and for that reason a method for the determination of distribution of foundry sand has been given considerable study by the Sub-committee on Grading.

Foundry sands may have the same A.F.A. Grain Fineness Number and yet possess entirely different properties. Table 1 shows sands of the same A.F.A. Grain Fineness Number but their texture, permeability and density vary widely depending upon the distribution of the sand grains.

In Table 1 sand No. 1 is the most uniform, while sand No. 4 is the most widely distributed. Therefore, to distinguish between sands of the same A.F.A. Grain Fineness Number, it is necessary to determine their relative distribution.

An exhaustive study of existing distribution methods was made by the Sub-Committee on Grading but it was found that

[1] Sand Grading Classifications, *"Testing and Grading Foundry Sands,"* American Foundrymen's Association (March, 1931), pp. 132-140.

Table 1

GRAIN DISTRIBUTION OF SANDS HAVING THE SAME A.F.A. GRAIN FINENESS NUMBER

	PER CENT RETAINED ON SIEVES			
Sieve No.	Sand No. 1	Sand No. 2	Sand No. 3	Sand No. 4
20	0	0	0	0
30	0	0	5	23
40	0	7	18	19
50	0	12	25	17
70	100	71	30	15
100	0	8	14	12
140	0	2	6	8
200	0	0	2	5
270	0	0	0	1
—270 Pan	0	0	0	0
AFA Grain Fineness No.	50	50	50	50
Permeability:				
Dry	127	111	95	85
Tempered	210	187	160	125
Density (dry) Grams per 100 cc	166	171	177	184
Green Strength (Tensile-oz.)	1.25	1.41	1.55	1.75

these were not suitable. The committee then undertook to develop the method which is described below.

DEFINITION OF DISTRIBUTION

Distribution is defined as the variation or uniformity in particle sizes found in a sand. The grain distribution numbers of a sand are defined as the spread of the sizes with respect to weight and according to the A.F.A. Sieve Series.[2] The spread is considered with respect to the midpoint or 50 per cent of the grain material.

Method of Determination A.F.A. Grain Distribution Numbers

From the Standard A.F.A. Fineness Test:

(*A*) Draw a line above and below the sieve retaining cumulatively half or more of the total grain. (This is designated as the "axis" sieve. See Table 2.)

[2] Fineness Test Standard, *"Testing and Grading Foundry Sands,"* A.F.A. (March, 1931), p. 88.

(*B*) Multiply the percentage retained on the first sieve above the "axis" sieve by 1; the percentage on the second sieve above by 3; the third by 5; and the fourth by 7; etc.

(*C*) From one-half the total grain subtract the total percentage of grain above the "axis" sieve. This is the "coarse" portion of the percentage of the grain on the "axis" sieve.

(*D*) To one-half the total grain add the total percentage of grain above the "axis" sieve. Multiply this sum by the "coarse" portion under (*C*), and divide the result by the total percentage of grain on the "axis" sieve.

(*E*) Add the final result obtained under (*B*). This sum divided by the total percentage of grain on all sieves is designated as the *Coarse Grain Distribution Number.*

(*F*) The Fine Grain Distribution Number is determined in a similar manner. Multiply the percentages retained on the first, second, third, fourth, etc. sieve below the "axis" sieve by 1, 3, 5, 7, etc. respectively.

(*G*) The "fine" portion of grain on the "axis" sieve is obtained by subtracting the total percentage of grain below the "axis" sieve from half the total grain percentage.

(*H*) To one-half the total grain add the total percentage of grain below the "axis" sieve. Multiply this sum by the "fine" portion under "G," and divide the result by the total percentage of grain on the "axis" sieve.

(*I*) Add the final result under (*H*) to the sum of the products under (*F*). This sum divided by the total percentage of grain on all sieves is designated as the *Fine Grain Distribution Number.*

(*J*) The sum of the Coarse and Fine Grain Distribution Numbers added to the smaller of the two is the *A.F.A. Grain Distribution Number.*

An Example of Determination of Grain Distribution Number.

The calculations for the determination of the A.F.A. Grain Distribution Numbers are given in Table 2.

DISCUSSION

It will be found convenient when comparing sands of similar distribution to use only the A.F.A. Grain Distribution Number but when comparing different types of foundry sand it will be

Table 2

CALCULATIONS FOR A.F.A. GRAIN DISTRIBUTION NUMBERS

On Sieve No.		% Retained on Sieve		Multiplier	Product	
	20	0.0		—	—	
	30	0.0		—	—	
	40	0.4		9	3.6	
	50	1.3		7	9.1	
	70	2.4		5	12.0	
	100	4.5		3	13.5	
	140	17.1	25.7	1	17.1	
	"Axis Sieve"			$\frac{(44.1-25.7)\ (44.1+25.7)}{22.1}$	=58.1	113.4
	200	22.1		$\frac{(44.1-40.4)\ (44.1+40.4)}{22.1}$	=14.1	
	270	21.8		1	21.8	
	Pan	18.6	40.4	3	55.8	91.7
		88.2 (50 per cent of grain = 44.1)				

Coarse Grain Distribution $= \frac{113.4}{88.2} = 1.29$

Fine Grain Distribution $= \frac{91.7}{88.2} = 1.04$

A. F. A. Grain Distribution Number $= 1.29 + 1.04 + 1.04 + 3.37$

Distribution expressed as $1.29 - \underline{3.37} - 1.04$

necessary to express the grain distribution as three functions, *i.e.*, Coarse Grain Distribution Number, A.F.A. Grain Distribution Number and Fine Grain Distribution Number. These are to be designated in the order given with the A.F.A. Grain Distribution Number underlined.

Table 3 shows the Distribution Numbers of a few hypothetical combinations. It will be observed from this table that distribution is entirely independent of the fineness number. Also the sand becomes more uniform in grain size as the distribution numbers decrease and conversely as the sand grains become more widely scattered the distribution numbers increase.

The Grain Distribution as expressed by this method is not intended to replace the A.F.A. Grain Fineness Number but rather to be used together with the Fineness Number to more completely define the sand.

The Sub-Committee have undertaken this work for the benefit of the industry at large and it feels that this method is accurate and rather easy to manipulate and when used with A.F.A. Grain

Fineness Number should be a definite asset to both producer and consumer in properly designating any foundry sand.

Table 3

DISTRIBUTION NUMBERS

Mesh	1	2	3	4	5	6	7	8	9
40	....	....	....	....	....	....	....	.....	.....
50	....	....	....	....	....	....	....	5	30
70	5	25	....	....	33⅓	25	30	5	
100	100	25	75	75	50	33⅓	25	30	30
140	....	....	25	50	33⅓	50	25	10	
200	....	....	....	....	....	....	10	25	
Coarse Grain Distribution	0.25	0.31	0.50	0.33	0.50	0.75	1.00	0.875	1.375
Fine Grain Distribution	0.25	0.26	0.33	0.50	0.50	0.75	0.50	0.975	1.275
A.F.A. Distribution No.	0.75	0.83	1.16	1.16	1.50	2.25	2.00	2.73	3.93

Graphic Method for Calculating The A.F.A. Grain Distribution Numbers

A.F.A. Grain Distribution Numbers may also be calculated graphically basing the coarse and fine grain material on the area included between the cumulative percentage of grain retained on and that passing the A.F.A. sieve series.

The data in Table 4 obtained from the A.F.A. Fineness Test of the Sand are necessary for a graphic description and for the calculation of the grain distribution numbers according to this method.

Table 4

SAND FINENESS DATA

Sieve No.	Material Remaining on Sieve Per Cent	—Cumulative Per Cent— Retained	Passed
20	0.0	0.0	0.0
30	0.0	0.0	88.2
40	0.4	0.4	87.8
50	1.3	1.7	86.5
70	2.4	4.1	84.1
100	4.5	8.6	79.6
140	17.1	25.7	62.5
200	22.1	47.8	40.4
270	21.8	69.6	18.6
Pan	18.6	88.2	0.0

In Fig. 1 the cumulative percentage of grains retained on the A.F.A. Sieve Series is represented by the curve (30, 44.1, 88.2), while the cumulative percentage of sand grains passing the A.F.A. Sieve Series is represented by the curve (88.2, 44.1, Pan).

The axis *GH* represents the center grain fineness of the sand.

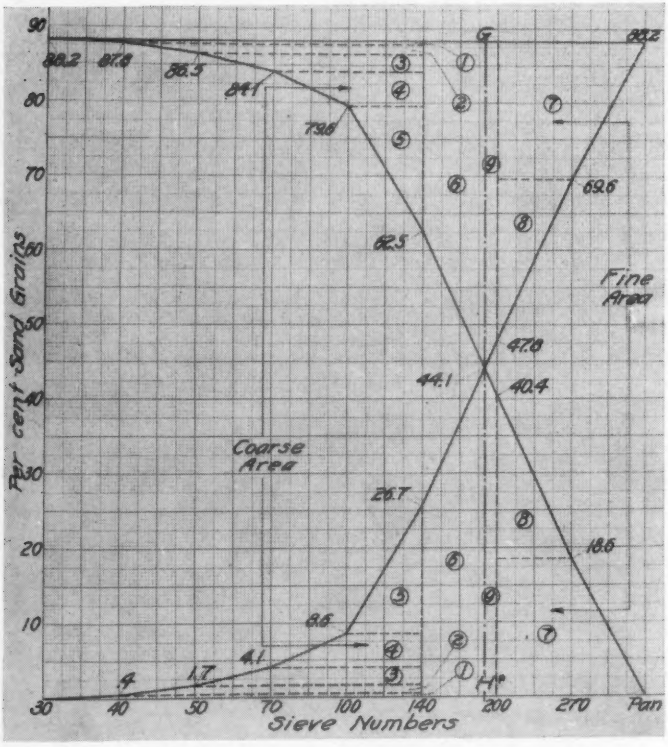

FIG. 1—GRAPHIC DESCRIPTION OF THE GRAIN DISTRIBUTION NUMBERS

The area to the left of the axis *GH* (*i.e.*, the area included between the points (30, 44.1, 88.2, *GH*, 30) is an index of the Coarse Grain Distribution Number while the area to the right of the axis *GH* (*i.e.*, the area included between the points 88.2, *GH*, Pan, 44.1, 88.2) represents the Fine Grain Distribution Number. The two curves will always intersect at the 50 per cent grain point; as the axis *GH* passes through this point it divides the grain into coarse and fine portions.

The calculations of the coarse and fine areas as well as the Coarse and Fine Grain Distribution Numbers are given in Table 5. These correspond exactly with the coarse and fine distribution numbers in the present A.F.A. Tentative Standard Method for the determination of Grain Distribution.

Table 5

CALCULATION OF GRAIN DISTRIBUTION NUMBERS ACCORDING TO THE GRAPHIC METHOD

Calculation of Coarse Area

$$2 \times \text{Area } 1 = 2 \times 0.4 \times \frac{4+5}{2} = 3.6$$

$$2 \times \text{Area } 2 = 2 \times 1.3 \times \frac{3+4}{2} = 9.1$$

$$2 \times \text{Area } 3 = 2 \times 2.4 \times \frac{2+3}{2} = 12.0$$

$$2 \times \text{Area } 4 = 2 \times 4.5 \times \frac{1+2}{2} = 13.5$$

$$2 \times \text{Area } 5 = 2 \times 17.1 \times \frac{0+1}{2} = 17.1$$

$$2 \times \text{Area } 6 = 2 \times \frac{44.1+25.7}{2} \times \frac{44.1-25.7}{47.8-25.7} = 58.1$$

113.4 Total

This result divided by the total percentage of grain equals the Coarse Grain Distribution Number.

$$\text{Coarse Grain Distribution Number} = \frac{113.3}{88.2} = 1.29$$

Calculation of Fine Area

$$2 \times \text{Area } 7 = 2 \times 18.6 \times \frac{1+2}{2} = 55.8$$

$$2 \times \text{Area } 8 = 2 \times 21.8 \times \frac{0+1}{2} = 21.8$$

$$2 \times \text{Area } 9 = 2 \times \frac{44.1+40.4}{2} \times \frac{44.1-40.4}{62.5-40.4} = 14.2$$

91.8 Total

This result divided by the total percentage of grain equals the Fine Grain Distribution Number.

$$\text{Fine Grain Distribution Number} = \frac{91.8}{88.2} = 1.04$$

A.F.A. Grain Distribution Number $1.29 + 1.04 + 1.04 = 3.37$

Distribution expressed as $1.29 - \underline{3.37} - 1.04$.

Respectfully submitted,

Sub-Committee on Grading

W. G. REICHERT, *Chairman*

PAUL BECHTNER

C. MATHIESEN

C. M. SAEGER, JR.

* This expresses the altitude of area 6.

Report of A. F. A. Committee on Industrial Hygiene*

To the Members of the American Foundrymen's Association:

This report is to advise the membership of the Association of the activities of their Industrial Hygiene Codes Committee, which is an outgrowth of the original Exhaust Codes Committee of the A.F.A.

For some time past, the A.F.A. has had representation on American Standards Association Exhaust Codes Committee Z-9, which committee has become more active in connection with developing exhaust codes in recent months. It was felt, however, by your officers of the A.F.A., that there was an urgent need to have the industry develop Foundry Process Codes and a Foundry Industry Code as promptly as possible in order to have recommended information available for the industry as well as for some of the various State Industrial Commissions and State Legislatures that are now working on the problems of applying either state codes or acts of legislature for controlling the dust hazard problem in connection with various processes in the foundry.

Your Industrial Hygiene Codes Committee membership is made up of representatives from various gray iron, malleable, nonferrous, and cast steel foundries, as well as having representation from various equipment vendors. There are already under development and nearing completion Codes on Grinding, Polishing and Buffing Equipment Sanitation, and one on a Code for Air Flow Measurement and Testing for Exhaust Systems. There is still another code quite well under way covering the Design of Exhaust Systems, and also one in the course of preparation on Foundry Parting Materials.

In addition to the codes enumerated above, we will shortly have under consideration Codes for Foundry Shakeouts, Core Knockouts, Core Grinding, Mold Conveyor Units, Sand Preparation Equipment, Chipping, Core Ovens, Pattern and Wood Working Machinery, Welding Exhausts, Dust Arresters, Collectors and Precipitators, General Ventilation, etc.

As rapidly as our committee completes a code, it is the intention to submit it to the A.F.A. State Policy Committees for their

* Presented before Detroit Convention Session on Safety and Hygiene, May 8, 1936.

comments and suggestions. It is hoped therefore with the wide circulation to the State groups, that there will be sufficient constructive criticism so that when the codes are finally issued as recommended standards for the foundry industry, they will be of great benefit to the foundry industry at large, and of considerable help to various State Legislatures and State Industrial Commissions should they so desire to follow recommendations set forth in the codes.

The foundry industry as a whole has been very active in many parts of the country in promoting and advocating dust control and occupational disease legislation, and it is our belief that the foundry industry has been very progressive as an industry in realizing the necessity of doing something for the abatement of occupational diseases. While it may be argued that it may not be necessary to develop codes and standards for the control of various foundry processes, we do, however, fully appreciate the fact that if we do not undertake the job of setting up our own industry codes, that some other organization is going to do it for us and in that case we may not be able to control what goes into the codes if others write them for us.

Respectfully submitted,

JAMES R. ALLAN
Chairman, A.F.A. Industrial Hygiene Codes Committee.

Progress of Safety and Hygiene in the Foundry—I

Medical Aspects[1]

By Roy R. Jones[2], M.D., Medical Adviser, Division of Labor Standards, Washington, D. C.

I feel very sure that many of you here are more capable of discussing progress in hygiene and safety in the foundry industry than I am. My experience is quite limited. I can assure you, however, of one thing—namely, that the group I have met in the foundry industry seem to me to represent the spearhead of attack by industry in this country, in their approach to the control of industrial health hazards.

From my association with your leaders in the medical and engineering control of foundry hazards, and from the inspiration I have found at this Convention, I can see why you have been so successful. May I suggest here that those in charge of Government foundry operations be invited to your next meeting of this character. I know they will appreciate an opportunity such as this, and gain much of value to them from what is to be learned here.

At this time, when practically everywhere those responsible are giving serious consideration to the prevention of occupational diseases and to the control of industrial accidents, it is encouraging to review the progress made by the foundry and allied industries in this field.

This review should prove advantageous for several reasons. It will stimulate more general interest in the adoption of effective preventive measures on the part of the entire industry. Also, in some quarters, and particularly in the case of certain specific occupational diseases, due to misinformation rather than lack of information, a panic-like situation exists. An unbiased appraisal of conditions, and a wide distribution of the facts revealed, should assist in relieving this situation. Furthermore, this review will afford us an opportunity to determine what particular phase of control needs further emphasis and study.

[1] Presented before Detroit Convention Session on Safety and Hygiene, May 8, 1936.

[2] Passed Assistant Surgeon, U. S. Public Health Service.

How Progress May Be Indicated

That progress has been made in the prevention of accidents is manifested by the great reduction in the number and severity of accidents as reported today, when compared with ten and twenty years ago. The foundry industry as a group has taken an active part in this national program directed toward the reduction of industrial accidents. Many individual establishments, large and small, have plant safety organizations, to which the management itself gives continuous attention. Marked progress has been made in the prevention of industrial accidents since the time such has been generally accepted as the employer's responsibility. There was a time when the foundry worker seeking life insurance was considered a poor risk, and the best he could obtain in the way of insurance was substandard. This condition does not hold today. Employees in the foundry are accepted as standard risks.

The progress made in the control of occupational diseases, however, is not to be estimated by any decrease in the number and severity of cases reported. Such diseases are usually chronic in nature, and develop after years of exposure to harmful environmental conditions. Because more cases are being reported is no indication that progress in prevention is not being made. On the contrary, because of our newer knowledge concerning the causes of these diseases, our increased interest in the problem, and improved methods of diagnosis, an actual increase in the number of cases reported is to be expected. Most of these cases will have resulted, however, from exposures experienced prior to the adoption of modern methods of prevention. Since success in the control of industrial health hazards is dependent upon our detailed knowledge of occupational diseases, their causes, where they occur, methods of diagnosis, and upon prevention methods and maintenance of safe working environment, our progress in this field may be truly indicated by the extent of our information of this nature.

General Problems of Hygiene

The basic processes involved in foundry work are as old as our knowledge of metals, and these processes, in their modification, have kept abreast of the evolution of other industrial operations. There is not, to my knowledge, any occupational disease or industrial health hazard peculiar to the foundry industry; with the exception of brass founders' ague, all have occurred more frequently and have been of more serious import in other industries.

In a paper of this form, we cannot discuss in detail all of the

industrial health hazards which, in times past and present, have been considered associated with the foundry industry. We may, however, mention some of the more important ones and consider how the problems have been and are being met. The more important industrial health problems associated with the foundry industry are those related to:

(a) General physical characteristics of the building
(b) Housekeeping practices
(c) Drinking water supply; lunchroom and toilet facilities
(d) Exposure to extreme temperatures
(e) Exposure to toxic or irritating dust, fumes, and gases
(f) Medical supervision

As in the case of the prevention of accidents, success in the control of industrial health hazards is primarily dependent upon the employer's attitude toward the problem.

In early times, foundry work was often carried out in cellars or sub-basement quarters, with no attention given to what is today termed "housekeeping." Irritating and toxic gases and fumes, particularly those of lead and zinc, often seriously affected the workers. Today few foundries are located in such unsatisfactory surroundings. Even average establishments, where but a comparatively few men are employed, are in many instances housed in buildings erected for the purpose, adequate lighting and good general ventilation being provided.

Improved furnace operations, the use of oil and gas as fuel by equipment properly installed and operated, prevent any nuisances or hazards developing from this source and are of distinct advantage in maintaining a healthful foundry atmosphere. Foundry operators, as a group, give serious consideration to housekeeping problems. Progressive foundry operators appreciate the importance of good housekeeping. Not only has it proven a definite benefit through reduced accidents and improved health of the worker, but it has stimulated the morale of the employees, who appreciate this interest shown by their employers, to provide a clean and safe place in which to work. Many managers will say that the time and money spent in maintaining a clean plant have proved a most profitable investment. We hear a lot about new methods for cleaning the foundry atmosphere and reducing the dust hazard by various mechanical means, but after all, I firmly believe more than half of the health hazards due to dust are solved by simply practicing good housekeeping, which costs but little.

As our knowledge regarding the control of industrial health hazards has increased, more emphasis has been placed upon adequate toilet, washroom, and lunchroom facilities. In many instances, the provision of satisfactory quarters of this nature in the foundry has been difficult because of the types of buildings and their location, but as a general rule, this responsibility has not been neglected. Many of the well-managed foundries today set an example to other industries, of how these facilities should and may be provided.

The open salamander, almost universally seen in the older foundries, often filled the shop with unnecessary smoke and occasionally produced harmful atmospheric concentrations of carbon monoxide. Such practice is seldom noted today.

The development and maintenance of mass production methods require a more orderly arrangement of individual processes, and the keeping of aisles clean and unobstructed. The mechanization of methods of transferring molten metal has not only made it possible for fewer men to be exposed to extreme temperatures, but also, with free aisles, has materially reduced the chances of accidental injury from falling or being spattered with hot metal. Goggles, shields and protective clothing, etc., are commonly used for personal protection.

Some of the older hazards have been practically eliminated, due to improvements made in plant design, housekeeping, and controlled processes. At the same time the industry has in more recent years been concerned with an increase in certain of the older hazards and a few altogether new ones. This has resulted from the amounts and the character of materials used, and in some instances from new processes which have been developed. Increased production, calling for the use of larger amounts of materials containing lead and zinc, naturally added to the dangers of exposure to such dusts and fumes. The modern foundry operators have taken measures to properly hood and exhaust the large receptacles containing molten metals, and as a rule, good general ventilation has been provided. Formerly, lead poisoning was frequently reported among workers in non-ferrous foundries. Due to the efforts that have been made to properly exhaust processes generating lead fumes and dust, we seldom hear of plumbism among the foundry workers of today.

Although the health hazards associated with the use of solvents have not been a major problem in the foundry industry,

in recent years they have found more extensive application in connection with the preparation of special cores and in the degreasing operation. Fortunately, effective methods for properly exhausting the toxic fumes are in most cases readily applicable to foundry processes and but few cases of poisoning from this source have been reported. In view of the fact, however, that new solvents are continually being developed for industrial purposes, it is necessary that control of hazards which may be associated with them be given constant attention.

Foundries today produce, as single units, large castings which formerly, if made at all, were cast in sections and assembled. Furthermore, they also produce more finished products than formerly, and the grinding, polishing, and buffing operations required are common foundry practices. Based on our newer knowledge of metallurgy, the use of chromium, manganese, vanadium, tellurium, and such metals, has in recent years become more common. As our knowledge has broadened concerning the toxicity of these materials, progressive establishments have provided protection for the workers exposed to these substances in the form of dust and fumes.

Whether or not deserving of such attention, the health hazard creating the most concern today is that associated with the use of silica. Foundrymen in general have appreciated this, and have developed practical methods for controlling such operations as are required in the preparation and processing of parting compounds and in the use of sand in sand-blasting operations.

CONTROL OF SILICOSIS PROBLEM

Since we are so greatly concerned with the question of silicosis, we may benefit by a brief review of the progress that has been made generally in the control of the silicosis hazard and the activities the foundry industry has inaugurated to solve the problem. This will, from a medical viewpoint, serve to indicate the attitude of the industry toward adequate protection of the health of its employees, as well as to show its progress in the control of such hazard. When we consider how many years passed, after foundry operators possessed knowledge of what caused lead poisoning and how it could be prevented, before the problem was commonly solved, and compare this with the short period which has been required to recognize the measures necessary for the control of silicosis in the foundry, the contrast is indeed encouraging.

For centuries it has been known that the industrial environ-

ments associated with certain dusty occupations tended to produce a disabling pulmonary condition known as "pneumokoniosis." Silicosis as a disease entity has been recognized as such but for a comparatively few years. Until recent times, hard rock mining, quarrying, and stone processing were considered the chief occupations furnishing an environment conducive to the development of silicosis. As specific information regarding the cause of the disease has been accumulated, the disease has been reported as affecting workers in a large range of occupations.

For convenience only, we shall review the accumulation of our knowledge of silicosis, to include our modern conception of the disease in five different periods:

The first period covers the years from 1871 to 1900. In 1871, Rovida first designated the condition "Silicosis" because of the excessive silica found upon chemical examination of the lungs of an individual dying of "pneumokoniosis." Little was accomplished in the way of prevention during this period; the matter was one of most concern to physicians on the Continent, who studied it chiefly from a pathological viewpoint.

The second period dates from 1900 to about 1912. The English authorities active at that time may be given the credit for initiating control measures on a large scale, through medical and engineering methods. Their studies of the disease as it occurred among the tin miners in England, the gold miners in South Africa, and the hard rock and coal miners in Australia stand out as landmarks in the scientific approach to the problem of prevention. These scientists studied the effects of exposure to various concentrations of silica dust based upon the weight of silica found in the air. A sanitarium was established in South Africa for the treatment of white Europeans employed there.

The third period dates from about 1912 to 1924. During this time, further advances were made in methods of measuring dust exposure. American physicians and engineers began research studies concerning the occurrence of the disease among hard rock miners. The Impinger method of air-sampling and the counting of the particles to determine the concentration of dust was developed. The need for considering the size of the dust particle was indicated when the fact was established that the changes produced in the lungs were due to particles under ten microns in their greatest dimension. The X-ray, although it was invented as early as 1895, was not perfected to the point where detailed

pulmonary pathology could be studied by such means until about 1912. Even at this later date, it was not nearly so efficient as our modern X-ray equipment.

The fourth period dates from about 1924 to 1930. During this period, the silicosis problem attracted attention in all civilized countries. Late in this period, we find references to its occurrence in various industries. The silicosis hazard in the abrasive industry and sand-blasting operations was reported upon in this country. As recently as 1930, it was not considered a serious hazard in these newer industries. It has been considered, however, as such in the past five years.

In November, 1930, the Committee on Pneumokoniosis of the American Public Health Association proposed a definition for silicosis, which is generally accepted today. It is as follows:

> "Silicosis is a disease due to breathing air containing silica (SiO_2), characterized anatomically by generalized fibrotic changes and the development of miliary nodulation in both lungs, and clinically by shortness of breath, decreased chest expansion, lessened capacity for work, absence of fever, increased susceptibility to tuberculosis (some or all of which symptoms may be present), and by characteristic X-ray findings."

Although since that time we have learned much concerning the action of silica upon the tissues, the role of infection, and other phases of the problem, none of our later findings have altered the wording of this definition.

During the last period, extending from 1930 up to the present time, several interesting phases of the problem of silicosis have developed. The foundry industry has been intimately associated with these new developments. Field studies have been conducted by various agencies; national groups have been interested in furthering our knowledge concerning the relationship of silicosis to tuberculosis; several important details as regards etiology, diagnosis, disability, and prevention have been revealed.

As is usually the case, when our knowledge concerning a condition is limited, particularly as far as the medical aspects are concerned, there is often a tendency to assume extreme attitudes. Some will neglect to appreciate the importance of the disease and others will over-emphasize the seriousness of the situation. As knowledge of the disease becomes more general, the problem is

viewed in its proper light and more effective means undertaken to control the hazard. When we consider the silicosis problem today, we realize we have much to learn regarding certain phases. Nevertheless, our progress can be considered highly satisfactory. With regard to the cause of the disease, the fact has been established that whether or not the individual will develop silicosis depends primarily upon the concentration of free silica in the air he breathes, the size of the silica particles, and the duration of his exposure. Although the presence of other dusts with the silica in the air breathed may hasten or retard the effects of silica inhaled, it has not been shown to be of extreme importance in relation to the final effect. It is clear that previous or concurrent pulmonary infection exerts a marked stimulating effect upon the reaction of the tissues to silica; that individuals with silicosis in an advanced degree usually suffer from pulmonary tuberculosis as well. For this reason, respiratory infection, developing among workers employed where there is even a minimum or potential silica exposure, must be given careful medical supervision. For the individual's own benefit, as well as for the protection of his fellow-workers, the person with active pulmonary tuberculosis should not be given employment or retained in a position associated with a potential silicosis hazard.

Considering all of the predisposing as well as the exciting factors causing silicosis, we know that in the individual case a definite diagnosis of silicosis cannot be based upon such a single finding as X-ray or other sign or symptom. We know that we must have detailed information concerning past and present occupational history, past and present medical history, and the clinical knowledge afforded by a complete physical examination and X-ray film of the chest.

Aside from these rather clear-cut ideas relative to the causes of silicosis, the role of infection, and the diagnosis, the question of disability due to the disease is better understood today. With a large percentage of workers in some industries showing evidence of the disease, yet apparently suffering no decreased capacity for work, it is obvious that a diagnosis of silicosis does not necessarily mean disability; that the condition progresses very slowly; and for that reason many workers with silicosis will no doubt suffer no disabling effects from the condition in the future, provided

respiratory infection is guarded against and the conditions under which they work are reasonably controlled.

The highest incidence of tuberculosis among industrial workers is found in the siliceous industries. What is also most important, the highest rate of meningeal tuberculosis among children has been found to occur in the families of granite cutters suffering from silico-tuberculosis. This indicates not only an increase in incidence, but also an increase in the virulence of the infecting organism as well.

Some of the studies which have been conducted to determine the nature and extent of silicosis developing among foundry workers have revealed certain interesting facts. From a published report of the survey made by the Massachusetts Commission, and from personal communications we have received relative to the situation in individual plants, it is apparent that silicosis is less frequent among this group of industrial workers than among employees in granite processing and hard rock mining. As would be expected, where the disease is less frequent it is also manifested in a less advanced degree. For instance, in Massachusetts it was shown that 8.8 per cent of a representative group of foundry workers had silicosis, as compared with 15.2 per cent of a similar group of employees in the granite industry. As regards the seriousness of the condition, but 2.6 per cent of the foundry workers with silicosis suffered a complicating pulmonary tuberculosis, as compared with 7.6 per cent of the silicotic granite workers.

I might mention a recent experience which illustrates the importance of pulmonary tuberculosis in the production of disabling silicosis among foundry workers, and the necessity of not placing those with tuberculosis where they may infect those also exposed to silica dust. A man was employed as a sand-blaster for more than fifteen years, and his death was attributed to pumonary tuberculosis. Fortunately, this man's medical record for the past fifteen years was available. His history revealed that without doubt he had chronic tuberculosis when employed. X-rays of his chest taken at different times during the last five years showed a gradual increase in generalized pulmonary fibrosis and the spread of tuberculous infection. In studying this case, it was found that four of this man's co-workers, all of whom were robust men when employed, had contracted pulmonary tuberculosis, three dying of the disease and one committing suicide when he learned he had tuberculosis.

We see here the worker chronically ill with tuberculosis having his condition aggravated slowly, but well men, coming in contact with him, rapidly succumbing to the infection. None of these men had worked with the man having tuberculosis more than six years.

Industrial medicine is primarily preventive medicine. Adequate protection of the health of workers in the foundry industry is dependent upon proper medical supervision, co-operating with plant engineers, the employers, and the employees. Keeping the workroom atmosphere reasonably safe is an engineering job, and it is necessary that the physician understand plant processes and the physical requirements necessary in the individual, so that the worker may be placed where he can safely carry on. Preliminary and periodic physical examination of employees is a common practice among the larger foundry establishments, and even many of those employing but a few men frequently will give similar consideration to medical supervision.

As a rule, the medical personnel employed in foundries work is in close co-operation with the personnel in charge of plant safety and engineering control. Fewer men are refused employment because their examination reveals possible evidence of silicosis, but serious consideration is given those signs which denote active pulmonary infection. Because of the interest of the operators in the control of industrial health hazards, such processes as shakeout, chipping, sand-blasting, and other dust-producing operations are in most plants isolated or carried out in such a manner as to prevent unnecessary exposure to the worker. Some are conducted as enclosed processes properly exhausted. In the sand-blasting of larger castings which cannot be carried out by enclosed methods, the work is done in special sand-blasting rooms. The operators are provided with positive pressure helmets which supply clean air through a hose from an outside source.

Based upon this knowledge of the causes of silicosis and what can be done to maintain a safe foundry atmosphere, it is logical to consider that the progressive plants practicing these principles of prevention have solved in a large measure the silicosis problem. That we may confidently expect this to continue on to the complete control of industrial health hazards associated with foundry work is indicated by the action of your organization in setting up an industrial hygiene section. Real progress has been made and will continue, through your study of working conditions among the plants in your group. Through this agency, you will be prepared

to advise all members of ways and means of maintaining safe working conditions, and this group, through its co-operation with other recognized trade, employer, and government agencies, will exert a beneficial influence upon the programs of preventive medicine as applied to industrial workers generally.

In closing, I wish to thank you for this opportunity to be here today, to take part in your discussion and learn first hand how your organization is striving to improve the working environment of foundry employees.

(*Discussion begins on page 576*)

Progress of Safety and Hygiene in the Foundry—II

Legislative Aspects[1]

By Voyta Wrabetz,[2] Industrial Commission of Wisconsin, Madison, Wis.

The underlying theory justifying workmen's compensation acts is that industry shall pay for the damages which result from industrial accidents,—damages which are evidenced by necessary medical and hospital expenses, wage losses during disability, or the loss of support sustained by those who are dependent upon a deceased employee. This responsibility of industry is no longer seriously questioned.

From the standpoint of responsibility as to cause, there really is more justification for requiring payment of compensation in cases of diseases of occupation than there is in cases of accidental injuries. More than 75 per cent of all accidents are humanly preventable, or rather more than 3 out of 4 accidents are due to someone's carelessness or neglect. Our experience indicates that about 87 per cent of accidents are caused by the human element. A large part of industrial accidents are attributable to either the injured employee or his co-employee. In these cases we do not question industry's obligation to provide compensation benefits and to provide safety devices or maintain safe practices in production.

In contrast with accidental injuries, we have diseases of occupation to any of which the employee usually cannot contribute anything, either in its development or to its prevention, nor does he acquire it from any form of carelessness which might cause an accident. The disease comes upon him so insidiously that he frequently scoffs at the idea that he is becoming diseased. He does not realize what is happening to him until it is too late.

In this development the employee usually contributes nothing as a causative factor. He is working in a place of employment provided by his employer. He works with materials given to him by his employer. He does not know the nature of these materials

[1] Presented before Detroit Convention Session on Safety and Hygiene, May 8, 1936.

[2] Chairman, Industrial Commission of Wisconsin, Madison, Wis.

with which he works and to which he is exposed. These diseases come to him while, and as a result of, doing his employer's work in the place and manner prescribed.

In the case of accidents, the employer may be justly chargeable with at least a part of the cause, but in the case of disease, the entire causative factor belongs to industry and, therefore, all the more reason that this employer should provide compensation benefits, because more often than not, workers have no knowledge of the imminent danger and even when taking the greatest precaution themselves, they cannot protect themselves against the unknown dangers which may lurk in the colorless, odorless fumes of poison gases, or the invisible deleterious substances hidden in the materials with which they work or in the industrially contaminated air which they must breathe. The full burden for providing employment free from disease hazard must rest upon industry. In the event of failure to meet this obligation, industry should bear its compensation burden.

It is difficult to understand the reason which prompts the argument that industrial accidental injuries should be fully compensated, but that slowly progressing insidious diseases, caused by exposure to industrial hazards over a long period of time, should not be compensated at all or at most should be only partially compensated. Such reasoning really permits one industry to operate without assuming the costs of its production in discrimination against another industry which carries its full load of such costs. In Wisconsin, both industry and labor concur fully in a program that provides adequate compensation benefits to employees who are disabled by reason of diseases of occupations as well as by reason of accidental injuries.

The Wisconsin legislature in 1919 attempted to clothe all diseases of occupations with the beneficent purposes of the workmen's compensation act. With the best of intentions, but with a minimum of words, the act was made to apply to diseases of occupations. Chapter 668, Laws of 1919, added to the compensation act just three words, namely, "including occupational diseases". Therein lay the seed of much difficulty. If the legislature, with our wise "hindsight", had used a dozen more words, it, as well as the Industrial Commission and the Courts, would have been spared the necessity of writing many thousand of interpreting words and taking additional legislative action. Nevertheless, we believe we have the problem solved so that legal rights of workers exposed to

occupational disease hazards are clearly defined and fully protected.

The complications became involved when the compensation act, as so meagerly amended, was applied to certain diseases. The original law had been drafted to deal with industrial accidents and it was soon discovered that diseases caused by occupation were something far different from occupational accidents. When a grindstone falls on an employee's toes or when a worker's hand is crushed between gears, an injury is sustained then and there. The necessity for surgical treatment and the consequent physical disability are immediately present. The conditions of liability are clearly established without any uncertain elements. Even with most diseases of occupations, such as metallic or gaseous poisonings, these characteristics necessary to compensation liability are actually and objectively present.

It was not until the silicosis problem presented itself, that the difficulty of making the compensation act—drafted for accidental injuries—applicable to all occupational diseases, became apparent.

To fully comprehend the problem and the inadaptability of the original compensation law to it, one must know something about silicosis, its nature, development and effects.

Medical science tells us that silicosis is a condition of fibrosis in the lungs caused by the inhalation of silica; that the damage is brought about by the chemical reaction of soluble silica, having a toxic or poisoning effect on the phagocytes in the air cells; and that in turn the air cells became necrotic, resulting finally in fibrosis of the tissues of the lungs. The whole result is, of course, a pathological or diseased condition in the lungs. Subject to continuing exposure to harmful concentrations of silica, these effects grow and develop, until the lungs are ultimately overcome and disability and incapacity occur.

In the meantime, the worker passes through all the stages, from full strength and vigor to total disability or death. Because the human lung is constructed with a greater capacity than the human system requires, considerable pathology may exist without any symptoms whatever noticeable by the person afflicted. As a disease it develops over varying periods of time, dependent upon the individual susceptibility of the worker and upon the concentration of the harmful dust. Generally it develops to its disabling forms only after a relatively long period of exposure. Indeed, if a worker develops the early stages of the disease only after long

exposure, disability rarely occurs and the person ordinarily lives a normal expectancy of life. In any event, the disease is treacherous because of its slow development — disabling symptoms appear almost unnoticed.

Under these circumstances the question of determining and assessing liability on a wage loss basis is not so simple. For instance, when is the employee actually disabled? How should the existence of disability be determined? What employer should be held responsible, assuming that there have been several employers during the period the disease has developed? Which insurance carrier shall be held liable?

It is obvious, therefore, that while legislation should be as simple as possible, certain fundamental elements should be provided for:

First: Compensation benefits should be provided only when the disease is definitely caused by a hazard of the employment.

Second: Liability should be made to attach to the last day of the last period of employment that caused disability. Payment by such last employer should not penalize him in the long run, because while one employer may pay in one case, another employer will pay in another, so that as a matter of insurance, the whole liability evens out. The advantage of thus fixing liability lies in the fact that the fundamental principles of workmen's compensation are retained, that is, speedy and certain payment without the necessity of litigation. These principles are lost in any plan to pro rate the liability among several employments, because any such plan subjects the whole problem to many vexatious questions and inevitably leads to uncertainty, delay and litigation. I believe that any attempt to so carefully allocate liability is a needless waste of effort.

Third: Insurance carriers must cover the liability of any employer who is in good faith entitled to coverage. If an employer complies with safety provisions aimed at the elimination of silica and pays his premiums, he is entitled to coverage and should have no difficulty in procuring it.

Fourth: Merit rating should be made especially applicable to silicosis. The employer who by proper methods and practices reduces the silica hazard to a point of safe concentration, should get definite credit for his accomplishment and should not be required to subsidize the bad methods and bad practices of his competitor.

Fifth: Adequate medical examination should be encouraged, but oppressive medical examinations should be discouraged. The silicosis problem cannot be completely controlled except by periodical physical examinations of employees by qualified physicians in order to properly place workers in employment and also to medically control those who begin to show symptoms. Such medical examinations should be made of those who are entering employment that involves silicotic atmosphere so as to keep out those who might have a special susceptibility to such dust. However, the right to medically examine employees should not be abused and employers should be educated to realize that oppressive medical examinations are not necessary and any such abuse should be prevented by legal means, such as the withdrawal of merit rating.

Sixth: Reasonable safety standards should be established by codes. Codes should provide for the elimination of deleterious dust and set a safe maximum dust concentration in the breathing zone of the worker.

Seventh: Definite provision should be made to discourage the discharge of employees who are not disabled and who may safely continue in the employment in which they are trained. If, notwithstanding such discouragement, such employees are discharged, they should be compensated at least in an amount which will enable them to rehabilitate themselves in some other employment.

The problem presented on the basis of full coverage may seem mysterious and overwhelming. With absolute confidence, on the basis of almost seventeen years of experience and study of this problem, I can assure you that it is neither. In the application of the law, the questions which arise, while sometimes difficult, are no more difficult than in cases of accidents. If employers and insurance companies as well as compensation boards and commissions will approach the problem calmly and reasonably from both scientific and factual standpoints, conclusions may be reached and procedures may be adopted with as much certainty as to the solution of the problem as in the case of industrial accidents.

Silicosis as such has been recognized only within relatively recent years and in Wisconsin more particularly since the occupational disease amendment to the workmen's compensation law in 1919. With the increased knowledge of silicosis and its association with the inhalation of silica in certain industries and particularly because of the depression, there has been an increase in the number of cases which have been compensated under the compensation law of this state. This increase in turn has of necessity

brought about an increasing cost of compensation insurance in the industries in which this hazard exists as compared with the rate in similar industries in other states.

There is a difference in compensation costs in Wisconsin as compared to such costs in surrounding states. Some of this difference is due to larger benefits payable under the Wisconsin law, but unquestionably some is due to the fact that diseases of occupations, including silicosis, are not covered in other states. For iron foundries the rate in Wisconsin is $4.49 per hundred dollars of pay roll as compared with an average of $2.65 for three surrounding states; in steel foundries $9.96 as compared with an average of $3.69; in aluminum and brass foundries $3.39 as compared with $2.06; and in malleable iron foundries $4.49 as compared with $2.65. This increase in premium must, of course, be recognized as an increased cost to those engaged in the industry in our state and while the difference in rates seems to be rather marked, reflected in cost of production, it probably is about one-half of one per cent of the entire cost of production.

As a compensatory factor, Wisconsin industries should be heartened by the fact that they are not harassed by many common law actions, such as are pending in other states. In one neighboring state alone there were approximately 600 cases before the courts claiming damages for a total of thirty million dollars. The burden of judgments entered in these suits is, of course, not reflected in compensation premiums, but it is just as effectively a part of the cost of production. Therefore, while there is a difference in compensation premiums in favor of other states, this difference is at least partially, if not entirely, offset by the cost of damage suits. Recognizing the greater desirability of definite liability in accordance with the workmen's compensation law, employers in that state have just recently succeeded in placing silicosis within the compensation act of that state.

Many suggestions are offered with the intent of reducing the accumulated burden of silicosis upon industry. Ignoring any suggestions which were patently without merit, two principal suggestions are usually offered: first, an arbitrary reduction of compensation benefits in silicosis cases and, second, that the compensation premiums covering the silicosis hazard should be borne jointly by employers and employees. Both of these plans were endorsed by many employees, but it is clear that the endorsement of either of these plans by employees is largely dictated by the

economic situation or condition in which the employees find themselves at the present time. Self-preservation is said to be the first law of nature and the necessity for wage earning for the support of families often urges men to endorse policies, waive rights and assume risks which under normal conditions might be repugnant to their better judgment.

There is no justification for the reduction of compensation benefits. A man is just as completely disabled and has just as much loss of earning power when he is totally disabled on account of silicosis as he is when he is totally disabled on account of the loss of both arms, or both eyes, or other physical handicap. Furthermore, disability due to silicosis is as much part of the cost of industry as accidental injuries and should be compensated upon the same basis and should be a charge upon the same sources.

The only real constructive approach to this seemingly vexatious problem is to place upon industry the burden of compensation costs and by so doing continue the urge to reduce this burden by eliminating the silica hazard at its source. The actual and complete removal of silica-laden air from the breathing zone of workers is, of course, the only ultimate answer to the whole question and this is the answer which is being made by industry. Wisconsin's experience shows that this is not an impossible task and if properly approached lends itself to ready solution.

Recognizing the need for a sincere attack on the problem of eliminating the hazards of silica and of other dangerous dusts and fumes, the Industrial Commission in 1928 appointed an advisory committee representing labor, industries, professions and others interested, to study the subject and make recommendations for necessary regulations. After two years of investigation, the committee made tentative recommendations which were submitted to public hearings in December, 1930. After revision and further public hearings, the orders were adopted by the Industrial Commission on February 10, 1932 and became effective on March 18, 1932.

In general, the code requires exhaust ventilation to be provided in connection with all equipment and processes which create harmful exposure to any dusts, fumes, vapors or gases, in proportions which may be injurious to the health of the employee exposed thereto. This requires that the exhaust ventilation shall be installed in a manner which will be effective in removing these harmful constituents at the source in order to prevent their entrance

into the breathing zone of an operator or of other persons in the vicinity and also to dispose of them in such manner that they will not re-enter any occupied area. In some cases, of course, this is impossible to do and when this is found, it is required that the operators or other persons in the vicinity be protected by means of suitable respiratory devices.

On the whole, the code recognizes that a concentration of dust containing less than five million particles of silica per cubic foot of air is not harmful and is probably never productive of disabling silicosis. Compliance with the code has demonstrated the fact that lower concentrations of dust have been attained.

These results have been attained because consideration of the tentative code on dusts and its final adoption centered the attention of employers in whose industries silicosis was a hazard upon the conditions in their plants. Since that time, namely during the last four years, much has been done to control or eliminate the silica content in the air breathed by workers. As one employer stated it, "dust legislation has set all foundry operators on their toes . . . in the prevention of pulmonary diseases." The same is true with respect to iron mines and granite cutting.

There has been intensive experimentation in the use of various types of respirators and helmets, exhaust systems and sandblast booths. An important activity which has reduced the dust count materially has been one of proper "housecleaning" or ordinary cleanliness. The accumulated dust of years has been removed by sweeping, by washing and vacuum cleaning. Shops have been painted white or light shades so that dust and dirt will show up more readily.

One large industrial concern involving foundry operations has reduced the dust concentration in practically every part of its plant to less than five million particles per cubic foot of air, thus making it impossible for new workers to develop silicosis. To accomplish this end, it was necessary to vacuum clean the entire plant, to build a huge hydraulic washing outfit to remove sand from castings, to maintain a dust counting laboratory, to install dust-removing apparatus and to keep floors properly "dampened down."

Another foundry operator has expended during the past two years approximately $177,700 in installing apparatus to remove dust and smoke from furnaces and "shake-outs," in adequately enclosing sandblasts and sandmills and in providing sand conveyors

and other devices. This operator has plans under way involving the expenditure of $75,000 more. Many other foundry operators have expended large sums of money doing similar work. During the period from October 1, 1932 to November 30, 1934, an iron mining company has expended $39,601.13 for X-ray, laboratory and dust counting equipment and fan installation, $80,007.88 prevention expenses, including special studies, extraordinary mine development and ventilation and $32,966.97 for other expenses, making a total of $152,575.98. Further development of the work being done in this mine will practically assure workers in the future a safe atmosphere from the standpoint of silica content.

An excellent illustration of results which may be obtained in the field of dust elimination is offered by an industry engaged in the crushing of quartz. This concern, which started in its present business only a few years ago, was housed in a poorly constructed building and, while an attempt was made to control the dusty conditions, very little success was obtained either in protecting the workmen or the residents in the vicinity of the plant.

Realizing the gravity of the situation, this firm proceeded with plans for an entirely new building, new machinery and equipment and for a new system for collecting and disposing of the extremely fine silica dust arising from their operations. A sum of approximately $500,000 was expended on this establishment, which was placed in operation early in September, 1934. As a result of this expenditure, the aggravating conditions which formerly existed have been entirely remedied, both within and outside of the plant.

As previously stated, the large foundries in several instances have spent considerable sums of money for purposes of dust elimination. I do not wish, however, to convey the idea that the large shops are the only ones that made progress in this direction, or that large expenditures of money are always necessary.

The smaller concerns have also made distinct progress at a proportionally lower expenditure. It must be remembered that the small shops have less mechanical dust producing equipment available and, therefore, have fewer and less expensive changes to make. In many cases all that was necessary was to conduct a thorough housecleaning of the foundry interior; that is, the removal of accumulated dust from beams, pipes and overhead structures, and the inauguration of a program of good housekeeping. Others made repairs to sand blast rooms, automatic blast equipment and tumbling barrels so as to make them dust-tight. In

all cases the repair of leaks in ventilating ducts, and possible increase in speed of exhauster fans greatly improved the efficiency of existing ventilating equipment. Operators performing dusty operations infrequently, or for short durations, were provided with proper helmets or respirators.

Because elimination of silica dust is the only remedy for the abatement of silicosis and because of what has actually been accomplished by way of silica elimination in a relatively short period of time, the urge to continued work and further development in this respect should not be diminished either by reducing the benefits which the workmen's compensation law provides nor by sharing the burden of such costs.

In some states, upon the enactment of an occupational disease law, employers have refused to employ men in whom a first stage or even a trace of the disease is found. For a short period of time Wisconsin had the same experience until it was learned that this precaution was not only unfortunate, but wholly unnecessary. This attitude of employers, aided and abetted by insurance carriers, was dictated by a fear of the payment of large amounts of compensation in the future. In actual practice, it was found that such fear was unfounded.

It is a fact, to which attention has already been called, that silicosis is ordinarily a disease contracted after many years of exposure and, therefore, men who after more than fifteen years of exposure are discovered to have only a trace or at most only a first stage silicosis, are actually no hazard to the employer. Such individuals seldom, if ever, develop a disabling silicosis, either per se or with complications. If permitted to remain in similar employment, such men could carry on in the same occupation for the remainder of their working lives. I believe that those who develop only the early stages of silicosis after many years of exposure are, in fact, better risks than most men who have never been exposed and whose susceptibility is quite unknown. Such men should not be discharged from their employment because they have developed a non-disabling silicosis.

This practice should be stopped. If an employee is discharged because he has a non-disabling silicosis, he should be paid a rehabilitation wage or, rather, (permit me to coin a new phrase) a "silicosis employment separation wage." Such men will have to seek employment in other industries and while so separated from employment because of silicosis will sustain wage loss even though

not disabled. In the case of a more skilled worker, the wage loss will occur either because of the necessity of procuring a new job at a reduced wage or because of the time necessary to acquire skill in an equally remunerative employment. In either case, the wage loss is directly due to silicosis and is as truly a wage loss as if actual physical disability had occurred.

Our records indicate that the accumulated liability of past years has now been substantially liquidated. The insurance company that carries about 60% of the insured compensation liability in the state has paid compensation in silicosis cases as follows:

Year	No. of cases	Amt. paid
1926	4	$ 17,767
1927	1	9,301
1928	3	12,592
1929	2	8,992
1930	7	43,279
1931	15	56,620
1932	20	67,936
1933	50	118,344
1934	19	40,537
1935	10	30,600

The records of the commission also indicate that the maximum silicosis load was disposed of during the years 1933 and 1934.

Although we have a few cases of silicosis still pending, the peak cost in Wisconsin has been passed at least two years ago. We believe that while the possibility of silicosis has not been entirely eliminated, the practical general control of the problem is assured and that this position has been attained without undue cost to our employers.

To maintain what has already been gained and at the same time gain the possible—the elimination of silicosis completely—greater progress and development must continue. The charging of unlimited coverage for silicosis as a direct and positive responsibility of industry supplies the urge for this continued effort. The assumption of this responsibility, free from fear or hysteria, will solve the problem of silicosis as well as of other diseases of occupations.

(*Discussion begins on page 576*)

Progress of Safety and Hygiene in the Foundry—III

Open Forum

Following the presentation of the preceding papers and committee report, the meeting was devoted to a discussion period or open forum.

PRESIDENT D. M. AVEY: I would now like to introduce our Forum Leader, Dr. J. A. Britton, Supervisor of Medical Service of the International Harvester Company, Chicago. Dr. Britton.

DR. BRITTON: Mr. Chairman—I agree with Dr. Jones, that there has been a very decided and aggressive tendency upon the part of foundries and industries as a whole to understand their health problems as such, and one of these health problems, namely, silicosis, has been given a great deal of intensive study.

During the many years of medical service in industry, there are a few very simple things that we have learned in the way of procedure. Manufacturing methods are changing every day, materials are changing, new combinations are made, new hazards are introduced. In order to keep pace with the situation, in order to have just a fair, honest judgment about what to do in a given situation, if you follow the simple rule of trying to understand the factors that make up a hazard, you will have something upon which to form a conclusion, something from which to start.

That sounds like A-B-C stuff. Let me illustrate. When I was taken into this industrial game it used to be the practice to send me around to various departments of foundries and then I was asked what I thought about the situation. Well, you know, I was a doctor, I had come through school and I thought I was supposed to know, and if I didn't have an opinion—I couldn't maintain my position. At least, that was what I thought.

Many times I could get away with it perfectly; I would look at things and give a very professional opinion. But as I have grown older, I have become a little more cautious. The important thing now before I can make a judgment, or before I can even afford to have an opinion is that I must really know something about the problem.

You do not need to have an expert come into your various

plants to tell you the hazard of many of these things. What you do need is to take time and assign men enough to list, and evaluate the importance of these various hazards. We are past the time, gentlemen, when the plant superintendent can say, "That is the plant engineer's job. And we are not busy now, so he has no helper, so we can't do it just now. But as soon as we get a little busier, then he can get at it." And then, as soon as the plant gets busy, "We have some jobs now and the engineer has to tend to production problems, but when he gets that done he will take care of it."

That statement is not far-fetched. This combination of deferred action is exactly what happens. You should have somebody designated, who has at least ordinary intelligence and some understanding of your particular processes, to go through, and list every single hazard and attempt to evaluate them—get some additional help if you need it—but put everything down in black on white, just exactly the way you do with your accident hazards. You have your safety committees that say, "Here is a press that needs a guard. Here is a wheel on which the guard is broken. And here is another place where something else is wrong." They list all of those, and then, when you have your monthly meeting, you explain how many of those hazards have been entirely taken care of and how soon the others will be corrected.

If you will do that on your industrial disease problems and your occupational disease hazards, you will eliminate many of them in short order.

I agree heartily with the men who today emphasize the importance of good housekeeping. In the dust disease game, if you have a location in your plant where there is considerable dust produced and you do not have a means of taking care of that dust and removing it, soon there is a lot of dust on the floor, and you keep stirring it up,—the same dust over and again. Then instead of the operator being exposed to the dust just one time during the day, he is exposed to the same dust many times.

There is just a word I would like to say about the relative difficulty of evaluating compensation for accidents and for occupational diseases.

If a man pinches his fingers, he knows how he got hurt and where he is hurt. His fellow workmen know where he got hurt. Nearly any surgeon knows what to do about it. Practically anyone,

layman or physician, can tell you how much he has lost in the way of function, and most anyone can tell when his temporary disability is over.

But what about occupational disease? There is much to do about occupational disease yet. If I were called upon tomorrow in Chicago to get expert knowledge by some physician who knows by actual experience what to do in occupational disease cases, I could probably find a few men who would know about one or two types of occupational disease, no one who had anything like a comprehensive knowledge of occupational diseases and no one at all who could be of much help with some of the new hazards that are associated with new manufacturing processes.

An occupational disease is hard to diagnose; it is harder to treat; it is very difficult to know when a person ceases to be disabled or whether he is going to be disabled permanently. It is a simple thing, if a man pinches his finger in a press because he hasn't any guard, to know what to do. You can put on a guard and he won't pinch his fingers any more. But the prevention of occupational diseases isn't so simple. And that is where our trained engineers come in and that is the big field of the future.

I am glad to be able to say a word about physical examinations. My associates and I have been examining men for twenty years for employment and making periodic examination in the shops, but there is one rule we always make and insist on. What we find in the examination of an employee is never used to his disadvantage. It is the easiest thing in the world to turn a man down who is looking for a job. Supposing you suddenly had a demand for 500 men in your foundry. Do you want green high school boys? Do you want men off the farms? No. You want men who have had foundry experience. And any man who has had foundry experience has been subjected to foundry conditions. It is the easiest thing in the world to turn down the man because he has a few little marks on an X-ray plate. But we must use our heads gentlemen. There are very, very few of those men who should be prevented from going back into a foundry providing you do not have too bad a condition in your foundry. We must understand the job, understand the exposure, but we also must not use poor judgment and let things happen which should not happen either to a man applying for a job or the man already working.

I was in Washington the other day and one of the men who

was discussing the labor side of a physical examination made this statement: "We don't object to the physical examination as such. We think it is necessary in determining physical capacity in occupational disease, and so on. But in certain districts"—I have forgotten where he said—New York or Pennsylvania—"the employment department has some reason why they don't want to employ a man and they don't want to tell him so. So they say, 'You are all right, if you pass the doctor.' They send him in to the doctor and the doctor shakes his head and says, 'We can't take him.' "

That is a terrible thing to charge to a self-respecting, scientific man. That ought not happen. That sort of combination can only result in disaster for everybody, misunderstanding and trouble. I hope the medical departments of the various foundries you represent stick to the facts, use the best brains the Lord let them have—and if you have any dirty jobs to do, do them yourself. Don't put them on the medical department.

PRESIDENT AVEY: The meeting is now open for discussion and questions from the floor.

MEMBER: One of the medical men here, stated silicosis would not necessarily bar a man from continuing on his job. I would like to know if primary silicosis would not make that man more susceptible to other diseases, as for instance, pneumonia? Whereas, if he were barred from further employment he might escape this pneumonia as a disease.

DR. BRITTON: We do not have any reason to think so. We see a good many such cases and, there are several industries in this country that have examined large numbers of men with the X-ray. And there are no figures to indicate or even suggest that an early silicosis makes a man more susceptible to pneumonia. There are in the literature statistics to show that a man who has an advanced silicosis usually dies of tuberculosis. But you are not finding very many of those cases in the foundry industry. And if you have a man from 35 to 40 years of age who has spent all of his working life in the foundry, it will be very surprising if you don't find some degree of fibrosis in his lungs. We are taking that type of individual very freely and easily and have no qualms about it at all. Nor do we take a man off his job who has a moderate fibrosis.

MEMBER: We have a man in our plant who is 59 years of age.

He has the first stages of a fibrosis condition. Would you be alarmed with a condition of that kind?

DR. BRITTON: What has he done all his life?

MEMBER: He is in the milling room.

DR. BRITTON: And he is 59. What is he doing now?

MEMBER: He is still in the milling room.

DR. BRITTON: If he has reached the age of 59 and he has only the first stage, he can't live long enough to die of silicosis.

MEMBER: Is it your contention a young man is in a more dangerous state with a first or second stage fibrosis than the older man?

DR. BRITTON: You know, there is one thing I didn't make clear—I did hint at it—is this understanding of your particular problem. In an individual case, don't have any opinion about an X-ray plate unless you have the whole history of the case. How old is the individual? Where is he working? Where do you propose to have him work?

I had a man come into my clinic at Northwestern the other day who was 40 years of age. He had what appeared to be a moderately advanced case of silicosis. I said to him, "What is your job?"

He said, "I am a chauffeur."

"Well, how long have you been a chauffeur?"

"For twenty years."

"You don't do anything else?"

"No."

"Well," I said, "there is something in here I don't understand. What was your first job?"

"Oh," he said, "I worked in a little foundry down in Kentucky, and I used one of those hoses that had sand in it."

Now, he had worked a year and a half on this job and then after a twenty-year interval he had the signs of his old trouble but he was still hale and hearty and going along good.

There is no rule. You have to use the best judgment the Lord gave you when you have an individual case. You must take all the factors into consideration, not just the one.

H. S. WASHBURN:[1] In Mr. Wrabetz's intensely interesting paper he spoke of one or two particular instances of concerns spending $180,000 or $130,000 on dust control. Presumably larger con-

[1] Plainville Casting Co., Plainville, Conn.

cerns. As a matter of information, in relation to the gray iron foundry business, which embodies a great many very small organizations, I wonder if he can tell us the effect in Wisconsin of installing proper dust control in a small shop?

MR. WRABETZ: All I can answer is that generally, really, the silicosis problem, as far as foundries are concerned, isn't a particularly bad situation. In other words, we do not have very many cases of silicosis developing in foundries. We have had some cases in small foundries. The insurance companies, of course, are going into these plants, and our deputies likewise, and they suggest compliance with the code by the installation of some dust removing device. But to answer your question specifically, I will say the mortality in the small foundries is relatively small.

As a matter of fact, I might say this, that three years ago we received applications in at the rate of 15 to 20 a month, and during the last eight months we averaged about one or two a month. Which is definitely the result of what has been done, not only in the large places, but also in the small ones, by controlling dust.

I think there is a man here who might answer more specifically on that question. That is Dr. Meiter, who has done a lot of work in that connection.

DR. E. G. MEITER:[2] The small foundries in Wisconsin have also been actively engaged in dust elimination. Our program has been to correct first, those conditions that lend themselves most easily to solution. By that I mean the introduction of good housekeeping, the removal of dust accumulations from building interiors, the repair of leaks in sand blast rooms, providing the proper sand blast helmets and dust respirators, and the physical examination of the men. As far as my own observations are concerned, this has not been a difficult program for the small concern. In fact, I believe some of the smaller foundries are in better condition from a dust standpoint than the larger ones because the necessary corrections were easier to make.

MR. WASHBURN: On this question of an examination, which includes X-rays of the chest mostly, isn't there great danger of having those X-ray plates read by incompetent people? Especially people who are away from the large cities and the large

[2] Director, Industrial Hygiene Laboratory, Employers Mutuals, Milwaukee, Wisconsin.

hospitals, where are they going to get expert reading of such pictures?

DR. BRITTON: That might easily be a real problem. Let me tell you what we did. We have some twenty odd units, scattered all the way from Hamilton to New Orleans. And when we adopt a company policy we usually extend it to all of our company units. We have doctors at all of these units. Doctors, like superintendents, vary in ability. Some of them are good surgeons, some of them are good pill doctors; some of them know something about X-rays and some of them don't. I do not allow my men to start off on their own interpreting a bunch of films.

We have X-ray machines in practically all of our units. Now, Monday I am bringing in one of my men. I have just installed an X-ray machine for him. He is to spend two or three days with my organization learning, not to read X-ray plates, but learning what not to do. Anything that looks suspicious to him at all, he is not to pass judgment on it until he has sent it up to me for a check. I want his opinion—I want his idea, yes, but he must be educated by experience and this under sufficient supervision.

If you as the head of a foundry decide to start a medical service which includes chest X-rays and you haven't had medical service before, you would be very foolish if you did not find out whether or not your doctor had any ability in that particular line.

As I told you a while ago, the easiest thing is to play safe. If there is a shadow in the plate that might be due to a faulty plate, which the doctor doesn't understand, if he does not want to take any chances at all he rejects the man. But that is wrong for the man and it is wrong for you. You can not learn these things right off. I do not think that anybody can be expert in reading an X-ray plate in a few weeks or a few months, but I do know from practical experience that I can take an intelligent, wide-awake young doctor and by reasonable supervision keep him from making too many mistakes.

MR. WASHBURN: My concern isn't as large as the International Harvester. We would have to depend upon outside medical advice. One of my men developed a very severe cough. He began to lose weight very rapidly. We haven't any hospital in that town. We have one four miles away. The local doctor took him to the hospital four miles away and three doctors in that hospital read pictures taken of him and diagnosed his case as

being in a very advanced stage of tuberculosis. The man happened to be a Spaniard, and it seemed the best I could do was to send him back to Spain. But it occurred to us, as a last resort, to take him to a large sanitarium. After two days of examinations they found he had a very severe case of bronchitis, but that it was almost over. We gave him a complete rest for two or three weeks and he has been working for several years now.

So, when we have to go to more or less local doctors in small towns, aren't we liable to run into a lot of trouble?

DR. BRITTON: Well, some doctors are not angels, and some doctors don't know very much and you are apt to run into trouble. You ought to have some way of controlling that situation. The only advice that I can give you from my experience is that it has dangerous possibilities, both for the men and for you, and you ought to give it thorough consideration before you establish a medical organization to do your work without first determining whether the doctors know by experience how to do what is required. In some of these places it is going to be hard to get experienced medical service.

MEMBER: I would like to ask Mr. Wrabetz if, in the State of Wisconsin, in cases of occupational disease, the decision of the Commission is final or whether or not the claimant can appeal the case to a common pleas court?

MR. WRABETZ: Under the Wisconsin law the Commission's decision on findings is final. The only appeal that may be taken from our decision is on a question of law or fraud, fraud on the part of the Commission, to the courts. That is all.

I might say, in these medical cases that we have no medical board but we have adopted the policy of appointing special physicians to make examinations in particular cases. In that way we are able to select experts upon the particular thing under consideration. And in a case of that kind, we might suggest that the man be sent a little farther away to a man who is competent to make the examinations.

MEMBER: In our state of Ohio silicosis has not yet been considered an occupational disease. Would some one be willing to state what he would consider a firm's responsibility when either the first or second stage of silicosis is discovered in an employee other than to take him off that particular job? I mean more in

the sense of what medical attention should be considered to be borne by the firm itself?

DR. BRITTON: I would like to state, before I answer that question, that I believe a comprehensive occupational disease law, such as Wisconsin has had, and Illinois now has, and some of the other states have, is fundamentally right. I think that any man, as has been stated before, who has an occupational disease, is just as much entitled to compensation as a man who is disabled from an industrial accident. If the man has silicosis, in any stage, and the man is disabled because of that silicosis—I am purposely leaving out the argument as to what I think a disability is—then he should be compensated.

Judging the disability of an occupational disease is not simple. The thing that amazes me every time I see an honest case of advanced silicosis is how that individual kept on working in spite of his condition. In other words, when you see a plate of a man who has a real disability from silicosis, you wonder if he has any breathing space.

Now, on the other hand, if a man has a few little strings of fibrosis across his lungs and somebody tells him he is disabled because of his silicosis, that is a different proposition. In other words, it takes a lot of fibrosis to disable a man. And when there is honest disability, then there is no question about the fibrosis. As long as there is any question about the fibrosis, or whether this is just verging on a first stage or not, there is no disability from that cause. The man might be disabled from something else, but not from fibrosis due to silicosis.

C. F. CLARKE:[3] A good deal of emphasis has been placed on the reading of the X-ray plate, but for the benefit of those also located in small towns, I think the first emphasis should be put on the taking of the plate. You can send a good many plates to a doctor or to a clinic to be read, but if the plate isn't well taken in the first place, it means nothing. When we first started to have applicants for employment examined as well as our regular employees, I thought we would have to deal with all our men as silicotics. According to the man taking and reading plates, they were all silicotics. We then sent the same plates to Milwaukee to be read at the clinic there, and we found the whole trouble was that the plates had not been taken properly. And they were kind

[3] Monroe Steel Castings Co., Monroe, Mich.

enough to give the operator in our local hospital instructions on the taking of pictures. Then we found out we could keep quite a number of our men.

DR. BRITTON: That is absolutely right. I was in contact with a factory the other day, which was threatened with a suit and they wanted some settlement and they brought the plates for me to read. They were the plates showing the worst looking condition I have ever seen. And they were made that way by the technique of taking the plate. If you over-expose or if you have the man move a little, you get pictures looking as if the man were dying of silicosis. That was my first hunch this was deliberately done in order to get a plate which looked bad.

MR. WRABETZ: I would like to ask Dr. Jones a question, as to what he would do if he were a doctor in a small town and couldn't take X-rays very well?

DR. JONES: In the first place, I think it is as impossible to make a diagnosis of silicosis from an X-ray film as it is to make one without an X-ray film. If we remember what we have learned in medicine, I am sure this will be evident. We have heard a lot of statements to the effect that there are no clinical manifestations of silicosis. Any man who is disabled by a pulmonary fibrosis of such development that the fibrosis will show in an X-ray film will also present other positive evidences which may be elicited by a thorough physical examination.

For one thing, he will show a marked change in his respiratory rhythm. The inspiratory phase of respiration is normally longer than the expiratory phase. An individual with marked pulmonary fibrosis will show this disturbance in respiration following exercise. He cannot breathe as rapidly as a person without fibrosis. The increase in pulmonary fibrosis causes a loss of the normal elasticity of the lung, and the individual affected cannot empty his lungs rapidly enough to breathe as fast as would a normal person. This difference is marked. You and I would probably breathe 40 to 50 times per minute following strenuous exercise, while the silicotic will be found, following similar exercise, to be breathing about 24 to 30 times per minute. Furthermore, the normal person will soon be breathing again at the normal rate, while the silicotic will continue to breathe at a slightly increased respiratory rate for many minutes following exercise.

It is true that this condition will be manifested by individuals

with bronchial asthma, but there are other findings which will aid in differentiating this condition from silicosis. The history and the presence of rales, etc.

I think that back of it all is this further thought—that if you are going to do industrial medicine at all, you must not fail to take an occupational history, and after you have had some experience you can very well tell whether the individual is giving a true history or not. With his complete occupational history in front of you, a complete past medical history as well as present complaints, and the facts revealed by careful physical examination, using your eyes and such methods as percussion, palpation, and auscultation, the basis of medical diagnosis taught in school, I am definitely sure you can tell in a large percentage of cases whether you are going to have to depend upon an X-ray film or not. In cases where the diagnosis is needed for compensation purposes, you certainly should have a good X-ray film. Furthermore, I believe you should have films of men who are to be put to work in positions constituting a potential dust hazard. This must be done to eliminate those with infection. I do feel there has been too much emphasis placed upon X-ray interpretation. You can have a blood smear made and it's not worth much unless the proper technique is used. The same applies to X-ray.

The problem of securing properly trained medical advisers for industry brings up the point I would like to emphasize. People get in the picture shows what the public wants—the type of picture show they want—and so it is with physicians. The schools are turning out or will turn out the type demanded by the public. Organized industry can do much to influence the proper training of medical men for their services. If we will recognize industrial medicine as a specialty, I think the medical schools will be turning out the sort of man we want. You wouldn't think of taking a gall bladder case to a pediatrician, and it is just as asinine to take a man possibly suffering from occupational disease to a pediatrician.

MEMBER: Are there any records to prove or disprove that a negro is any more susceptible to silicosis than a white man? Has it been your experience they are?

DR. BRITTON: I don't like to answer that question with a yes or no. In Chicago the average death rate from tuberculosis is about 60 per 100,000 population. If you split that into colored and

white, the tuberculosis death rate is about 55 for whites and 300 for colored.

Many people have argued that is racial susceptibility. Maybe it is—maybe there is something to that. But let me paint you a picture of the average colored man. Eliminate the two or three common jobs, you all know about, that are available to the colored man. What do the rest of them do? They take the rottenest jobs, the dirtiest jobs, the most irregular jobs, the poorest paid jobs, and what is the result? They live in the poorest houses. They pack in sometimes three or four families where one family should be. Their food, when they have a pay check, is good, and when they haven't a pay check, is little. And so on down. You can visualize the rest of it.

I maintain this, that is you take a colored man and treat him to a fair living condition in any community, his expectancy is about as good as the next fellow's. And you take a white man, or a group of white men, and subject them to the condition that the average negro in the big city is subjected to at the present time, and all disease rates will go up, pneumonia, kidney disease —and if he happens to work in a dusty place, he probably will get sick quicker than the other fellow from his dust exposure. I do not think that racial susceptibility has very much to do with it. I think it is a socialogical and economic problem.

MR. WRABETZ: I agree with Dr. Britton. It just so happens I read an article by Prof. Boaz of Columbia University yesterday in which he said there was no such thing as racial predisposition. That if the races were all put on the same basis, they would all react about the same from the standpoint of intelligence, resistance to disease, stature and almost everything else.

MEMBER: Dr. Britton, I understood you to say you give periodical examinations to your employees. Is that done once every year? And do you examine periodically some employees more often than you do others? For instance, do you give those examinations to the sand blast men more often than you would the grinder or the chipper or the molder or foundryman?

DR. BRITTON: The general plan calls for a periodic examination of one year intervals of everybody, not forgetting the superintendent and his staff. If you are going to examine people in a foundry, don't pick out this dirty job and that dirty job, but go right down through. And you will be surprised what you find

among your foremen. The periodic examinations of the less exposed people come under the regular plan. If for any reason there is anything found that might be suspicious, anything we might want to follow from a medical standpoint, I mean, any disease exposure, then we see that man every month, every three months, every six months, whatever the particular conditions seem to indicate. We classify our examination cards so that those we want to see again are brought up regularly.

I can't help emphasizing again, just as I said in starting, that while you are largely thinking in terms of silicosis, a dust hazard, your foundries have other hazards that are just as important. Make your occupational hazard surveys. Have a setup which will tell you month by month how many of those still exist and how serious they are and what your plans are to take care of them. There are a few of them that can't be taken care of but most of them can. Concentrated intelligent effort is the secret, I think, of taking care of this occupational disease situation.

Report of Steel Division Committee on Radiography

C. W. Briggs[1]: A committee to study radiography was first discussed last year, and during this present year the committee members have been appointed and a preliminary study has been made of the subject. The members who have been appointed on this committee are: C. W. Briggs, Naval Research Laboratory, Anacostia, D. C., *Chairman;* J. A. Capp, General Electric Co., Schenectady, N. Y.; J. R. Hewitt, American Manganese Steel Co., Chicago Heights, Ill.; J. H. Locke, General Steel Castings Corp., Eddystone, Pa.; L. C. Wilson, Reading Steel Castings Co., Reading, Pa., and E. J. Ash, Watertown Arsenal, Watertown, Mass.

We were instructed by Mr. McKinney, Chairman of the Steel Division, to look over the general field of radiography and to decide what could be done to benefit the A.F.A., especially the Steel Division. We have only had one meeting, and that was yesterday, but we anticipate several in the near future and hope that by next year we will have a real report to present.

There is one project we have outlined and that is we plan to present before the A.F.A. the methods and technique of both gamma-ray and x-ray radiography in full so that they will be at hand for all foundrymen to use or to refer to if they so desire.

It has been proposed by the American Society for Testing Materials, in their June meeting, to conduct a symposium on radiography. It is planned to present in detail the two methods, gamma ray and x-ray radiography. If this is done, the symposium will be published and will be accessible to everyone. I doubt very much if the American Foundrymen's Association will reprint that work. However, if the A.S.T.M. does not publish the radiographic methods in full so that anyone can carry out radiography in an intelligent way, then the committee will prepare a paper on x-ray and gamma ray methods so that they will be available to the foundrymen.

We studied various other plans of committee action and decided that, in the very near future, we would concentrate most of our energy on a "Study of the Improvement of the Qaulity of Castings by Radiography Within the Industry." In this regard the committee does not refer to a study of inspection methods between the steel casting manufacturer and the consumer of castings. We are primarily interested in acquainting the foundrymen with the radiographic methods and adapting them for their own information so that they will know more about the internal characteristics of their product and what is involved if radiographic examination is prescribed. The committee feels that, among other things, this will mean a study of various castings that have been in service for a certain period of time; for example, such castings as, due to a reduction in wall thick-

[1] Division of Physical Metallurgy, U. S. Naval Research Laboratory, Washington, D. C.

Note: This report was presented at a meeting of the Steel Division at the 1936 Convention of A.F.A. in Detroit, Mich.

ness, or the like, had to be taken out of service. We hope that we may be able to radiograph some of these castings and ascertain to what extent defects are present. This has never been done and it will prove very interesting.

We have also planned on doing several other things along that line so that we may obtain information on how important defects are, and which are the most injurious ones.

P. E. MCKINNEY[2]: When we were considering subjects that would be of particular interest from a technological standpoint, we considered that this question of radiography was one that would probably be coming to the fore very rapidly in steel foundry practice. The purpose of this committee, as a service committee for the steel foundry industry and for the Steel Division of the A.F.A., is to let our members know what it is about, and if possible, to familiarize our own people with the limitations, the advantages and disadvantages of radiography so that we may more intelligently consider this method of examination of castings. As Mr. Briggs has said, it is not primarily an inspection tool, but a means to getting a better idea of what our product is.

In the early uses of radiography, there has been a good deal of criticism of the method due to the fact that the people who are handling it, are not sufficiently familiar with interpretation, and possibly some of them are not as familiar as they might be with foundry practices. Now, the only way to correct that is to get the two angles of it, that is, the foundry significance of the conditions that are found and the methods of finding them, so that they are of value to the people who are studying the characteristics of the castings.

CHAIRMAN R. A. BULL[3]: I can very heartily endorse that, Mr. McKinney. I am prompted to ask Dr. White of the University of Michigan if he will contribute something because the University of Michigan has x-ray equipment which they have used for 5 years for the examination of steel castings in a commercial way.

DR. A. E. WHITE[4]: I do not know as I have quite so much to say on this particular subject as I have possibly on the examinations which we have made recently with regard to the casting practice found in a number of different plants.

We should approach the question of x-ray examination with a good deal of sympathy and feel that it is a tool which should be used with discretion, for the reason that one may get disappointing results if its operation is not properly carried forward.

I would venture as a word of warning that everyone cannot use an x-ray unit and get acceptable findings. If one gets unacceptable findings, it is apt to be misleading to the client, and, furthermore, it is apt to prove quite embarrassing to the producer of the steel castings. That is, there are certain details in the operation of the x-ray which, carried out in a proper manner, will disclose defects if they exist, and if not carried forward in a proper way, will fail to find those defects. We should have a

[2] Metallurgical Engineer, Bethlehem Steel Co., Bethlehem, Pa.
[3] Consultant on Steel Castings, Chicago, Ill.
[4] University of Michigan, Ann Arbor, Mich.

very sympathetic appreciation of the value and the use of the x-ray. I say this because, of course, there are persons who feel that x-ray work can be done by almost anyone. These persons are apt to cause a good deal of trouble both to the customer and to the client. It is relatively a new tool, although we have had it in use for 5 years at the University, and it has been in use to a limited extent for 10 years or more in the industry. But I still feel a word of caution is desired with regard to it.

Of course, when one examines forgings and sections such as those that are going into Boulder Dam, where the x-ray examinations have been made by the thousands, probably up to a hundred thousand or more, a great deal of technique has been developed and the findings there are absolutely to be relied upon. But where the x-ray examination is done in a sporadic manner, we must consider possibly a good deal of caution must be taken in the manner in which the work is done. That is particularly true with regard to castings, because, of course, in most cases castings have very decided changes in section, changes in shape, and you have to see that the rays are essentially at right angles to the section that is being examined. Unless that is done, it is of no use whatever.

So my own feeling with regard to this matter is that everything should be done by this body and this organization to encourage the use of x-rays. I think it is rather vital to the foundry industry because you are in competition with rolled sections, welded sections, forged sections. You start out under somewhat of a handicap in some cases, as your costs of producing the castings in some cases may be higher than the cost would be if sections were produced in some other manner. Therefore, ways and means must be found to assure the client that the castings furnished are absolutely sound. One of the tools to determine that, of course, is the x-ray.

I feel this body should do everything it possibly can to encourage and spread and disseminate the use of the x-ray. But in doing so one must recognize that they must attempt to educate the clients or the purchasers of castings with regard to just what has been brought out, what can be brought out and what cannot be brought out.

J. M. SAMPSON[5]: There is one thing that I believe should be done before too many conclusions are drawn from x-ray examinations of castings now being made. I believe it is very advisable that a fairly good volume of radiographic work be done on castings that have given yeoman service over a long period of years. If we confine ourselves to the examination of new castings only, certain unwarranted prejudices may be piled up against the steel foundryman that will be difficult for him to live down. He should have an accumulation of evidence supporting his claim that certain defects along certain lines and certain sections subjected to certain stresses are not harmful.

CHAIRMAN BULL: Obviously, that is a very important point. It is like establishing the relationship between the x-ray illustration of the internal defect and the factor of safety of the part, is it not? In other words, as I understand your point, used material that we know has performed satisfactorily should be x-rayed to get a unit of measure regarding the observed defect and the actual serviceability of the material.

[5] Foundry Engineer, General Electric Co., Schenectady, N. Y.

Behavior of Manganese in the Cupola

By M. T. Davis, III,* Ontario, Calif.

The author conducted a series of tests to determine the loss of manganese in a 36-in. diameter cupola. The objects of the study were (a) to study, quantitatively, cupola manganese losses and (b) to establish a relationship between the losses and the position of the charges in the cupola. He ran 3 series of tests varying the method of charging and in the various cases recorded the manganese losses. The results of these tests are given in this paper.

1. Recently the author had the opportunity to make a study of manganese losses in a 36-in. cupola in the plant of the Kanawha Mfg. Co., Charleston, W. Va., and the results of this study are recorded in this paper. The object of the work was (a) To study, quantatively, the cupola losses of manganese, and (b) To establish a relationship between losses and the position of the charges in the cupola.

2. The cupola records of 36 different heats were used as data. These heats were divided into groups, according to the length of heat or position of the charges. Three general groups were selected:

(1) a long series of high test cast iron heats, not preceded by ordinary cast iron mixtures,

(2) a long series of high test cast iron heats, preceded by ordinary cast iron mixtures, and

(3) a short series of high test cast iron heats, preceded by ordinary cast iron mixtures.

Groups 2 and 3 were subdivided according to the number of preceding charges of plain cast iron. Group one was subdivided to show the effect of a lower manganese content.

3. Loss of manganese was obtained by subtracting the actual analysis of a given tap from the calculated analysis of the same tap. Calculated analyses were based on the chemical analyses of

* General Electric Co.

Note: This paper was presented at a session on Cast Iron at the 1936 Convention of A.F.A. in Detroit, Mich.

raw materials in the charge. Raw materials were sampled properly so that representative analyses were assured. When a tap was the last of a given mix, the calculated analysis was based on the proportions of each mix which should exist in that tap.

4. Only averages of the original data are included, since the original data would cover many pages and confuse the reader. All averages are of four or more heats unless otherwise noted. Individual values showed a maximum variation of 20 per cent from the averages given. Normal variation was 3 to 8 per cent. The values listed in the data are percentages of the manganese charged into the cupola.

5. Our chief interest was in the manganese variation for high test cast iron. Typical mixes and analyses are shown in Table 1.

Table 1

TYPICAL HIGH TEST MIXTURES

Charge	Analysis, per cent	
	Calculated	Actual
Steel Rails (70%).....650 lb.	Si.....1.36	Si.....1.00–1.50
Hi-test returns (30%)..350 lb.	Mn.....1.14	Mn.....0.45–0.90
7 Silicon Briquets *	P.....0.08	P.....0.05–0.25
2 Manganese Briquets **		T. C.....2.90–3.15

* Silicon Briquets weighed 2½ lb. each and contained 1 lb. silicon.
** Manganese Briquets weighed 3½ lb. each and contained 2 lb. Mn. and ½ lb. Si.

6. The high test series were usually followed by low test, or ordinary cast iron of the composition shown in Table 2.

Table 2

TYPICAL ORDINARY CAST IRON MIXTURE

Charge	Analysis, per cent	
	Calculated	Actual
Machine Scrap.....750 lb.	Si.....2.10	Si.....1.80–2.00
Pig Iron.....250 lb.	Mn.....0.75	Mn.....0.60–0.80
	P.....0.10	P.....0.25
		T. C.....3.70

The calculated analysis for the low test mix shows that 0.75 per cent Mn. was charged into the cupola.

7. The high test series was usually preceded by a mix for chilled car wheels of the composition shown in Table 3.

Table 3

TYPICAL CHILLED CAR WHEEL MIXTURE

Charge		Analysis, per cent — Calculated		Actual	
Wheel Scrap	600 lb.	Si	1.05	Si	0.90–1.05
Low Si. Pig	300 lb.	Mn	0.80	Mn	0.55–0.75
Steel Scrap	100 lb.	P	0.11	P	0.25
				T. C.	3.70

The calculated analysis for this mix shows that 0.80 per cent Mn. was charged into the cupola.

8. Data on cupola operation are given in Table 4.

Table 4

CUPOLA DATA

Diameter (inside), in.	36
Type	Whiting
Tuyere Ratio, per cent *	30
Blower used, type	Centrifugal
Cupola height to charging door, ft.	14½
Bed height, in.	48 to 50
Type of coke	By-product
Coke charges, lb.	130
Size metal charge, lb.	1000
Limestone flux used, lb. per charge	30
Volume of air used, cu. ft. per min.	2300–2500
Iron to coke ratio	8.5 to 1
Melting rate **, lb. per hr.	7000
Air pressure, oz.	6 to 7

* An auxiliary windbox, set directly above the tuyere windbox, with openings into the regular windbox, was used. Air from blower passed directly into this, and was forced down into the lower box and through the tuyeres.

** Calculated from time wind on to wind off.

The high test iron charges were placed in the cupola by hand. Steel rails were first charged over entire area. Returns and briquets were placed in the center of the charge and in the center of the cupola.

9. No temperature readings were made as a pyrometer was not available. A rough estimate is that the temperature of the metal reached a maximum about five taps after the high test cast iron had started to come over the spout. It probably maintained this maximum until the low test iron started to appear. The maximum temperature for the high test cast iron was close to 2700 deg. F. as it came over the spout.

Discussion of Results

Group 1

10. Group 1 (Table 5) is the most informative section of the data. It shows a clear trend toward greater losses of manganese as the heat progresses. Graphically it appears as in Fig. 1.

11. As the cupola heats up, the oxidation of manganese increases. If the heats were very long, the loss approached a constant value but the heats considered in this study are too short to show this effect.

12. At the end of a high test series, the loss is reduced slightly as this iron becomes diluted with the new low strength mix. This

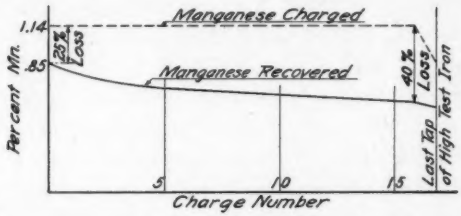

Fig. 1—Graphic Representation Showing Trend Toward Greater Losses of Manganese as the Heat Progresses.

Table 5

Cupola Manganese Losses—Group 1

	Calculated Analysis=1.15 Mn. Average of 4 Heats		Calculated Analysis=0.92 Mn. Average of 4 Heats	
Charge No.	Mix	Per Cent Loss	Mix	Per Cent Loss
1	Hi-Test	25	Hi-Test	3
2	"	27	"	4
3	"	30	"	14
4	"	32	"	17
5	"	35	"	15
6	"	35	"	20
7	"	39	"	14
8	"	41	"	15
9	"	42	"	20
10	"	43	"	23
11	"	40	"	37
12	"	44	"	37
13	"	45	50% Hi-Test 50% Low Test	32
14	"	46		
15	40% Hi-Test 60% Low Test	28		

is due to the lower manganese content of these taps. Examination of data for the taps at the end of a high test series shows conclusively that the ordinary cast iron (lower in manganese) has a better recovery of manganese than the higher manganese charges. For three taps, consisting of 100 per cent of the ordinary cast iron mix, the loss averaged 11 per cent. For three taps averaging 90 per cent high test cast iron and 10 per cent ordinary cast iron the manganese loss was 40 per cent. The same effect is shown by comparing the two divisions of Group 1. The division, containing 0.92 per cent charged manganese, showed much smaller losses than the heats with 1.14 per cent manganese.

13. Evidently most of the charged manganese above 0.80 per cent is burned out of the cupola, particularly if the mix is high in steel. If high manganese is to be obtained, it must be introduced partly in the ladle, and not in the cupola alone. It should be noted, however, that in the mixtures considered here, the extra manganese in the high test charges was added in the form of briquets. There is some evidence to show that a more diluted form of addition would give lower manganese losses.

Group 2

14. Group 2 (Table 6) includes long heats of high test iron, preceded by a low manganese mix. It is divided into three sections, depending upon the position of the series in the cupola.

15. All three series show the same general trend. The loss increases approximately 10 points for a series of ten high-test charges. The last taps of each series shows the expected decline in losses, due to the infiltration of the low manganese charges.

16. There is no strong relation between the loss of manganese and the position of the series in the cupola. The latter series show no greater losses than the earlier series. Evidently cupola temperature has some effect on the loss of manganese. High steel mixes melt at a higher temperature than ordinary cast iron, and the longer the high steel series, the hotter the cupola and the greater the loss of manganese. This seems to be substantiated by a comparison of groups 1 and 2. The series of group 1 show smaller losses for the first few charges but have larger losses at last due to their greater length.

Table 6

CUPOLA MANGANESE LOSSES—GROUP 2

	—Average of 7 Heats—		—Average of 4 Heats—		—Average of 2 Heats—	
Charge No.	Mix	Per Cent Loss	Mix	Per Cent Loss	Mix	Per Cent Loss
1	Chilled Wheel		Chilled Wheel		Chilled Wheel	
2	"		"		"	
3	"		"		"	
4	"		"		"	
5	"		"		"	
6	"		"		"	
7	Hi-Test	30	"		"	
8	"	29	"		"	
9	"	32	"		"	
10	"	35	"		"	
11	"	36	Hi-Test	27	"	
12	"	38	"	31	"	
13	"	37	"	39	"	
14	"	41	"	40	"	
15	55% Hi-Test 45% Low Test	29	"	41	"	
16	Low Test		"	43	"	
17	"		"	37	Hi-Test	17
18	"		75% Hi-Test 25% Low Test	39	"	25
19	"		Low Test		"	34
20	"		"		"	35
21	"		"		"	33
22					"	42
23					"	37

Group 3

17. Group 3 (Table 7) consists of short series of high test iron preceded by a low manganese mix, and followed by ordinary cast iron. It is divided into three sections, depending upon the position of the charges in the cupola.

18. All three sections show the effect of dilution caused by the adjoining manganese charges. The loss is noticeably lower for the first and last taps of a series. It is to be noticed, however, that a 32 to 38 per cent loss is suffered by the second tap of all divisions. A study of groups 1 and 2 indicates a lower loss for the second tap but in all three groups the effect of the adjoining

low manganese charges does not penetrate much farther than one, or sometimes two charges. The high loss attained by these short series suggests that their temperatures are nearly as high as for the longer high test series.

19. The later series do not show higher losses than the early series. The temperature necessary for melting the steel in high test cast iron, and the fact that a high percentage of manganese was charged with this mix, seems largely responsible for the high losses of manganese in the shorter series. Of the two reasons, the latter is probably more important.

SUMMARY

20. From the data submitted in this paper, the following conclusions* may be drawn:

(1) In a long series of charges of high test cast iron, there

Table 7

CUPOLA MANGANESE LOSSES—GROUP 3

	—Average of 2 Heats—		—Average of 4 Heats—		—Average of 4 Heats—	
Charge No.	Mix	Per Cent Loss	Mix	Per Cent Loss	Mix	Per Cent Loss
1	Low Test		Chilled Wheel		Chilled Wheel	
2	"		"		"	
3	Hi-Test	25	"		"	
4	"	35	"		"	
5	"	40	Hi-Test	32	"	
6	"	40	"	39	"	
7	50% Hi-Test 50% Low Test		"	38	"	
8			45% Hi-Test 55% Low Test	28	"	
9					"	
10					"	
11					Hi-Test	27
12					"	32
13					"	34
14					55% Hi-Test 45% Low Test	23

* These conclusions are based on the data from our 36 in. cupola. The quantitative results are peculiar to our own cupola, but it is felt that the general relationships are true for all cupolas. A study, along these lines, for any particular cupola, will reveal the points were extra manganese is needed in order to control that element.

is a gradual increase in the cupola loss of manganese. In the cupola studied (36-in. dia.), the loss was 25 per cent at the beginning and 40 per cent near the end.

(2) The smallest losses of manganese occur in the first and last charges of any particular series of high test cast iron. This effect, due to adjoining charges of low manganese metal, does not penetrate much farther than one charge into the high test metal.

(3) High temperatures are partly responsible for high losses in manganese and, therefore, long heats of high test cast iron ultimately attain higher losses than shorter heats.

(4) The most important determinent of the loss of manganese is the amount of manganese which is charged into the cupola.

21. With regards to compensating manganese additions in the cupola, the author wishes to point out that the study shows that extra manganese in the form of manganese briquets did not raise the ultimate manganese content sufficient to justify this method. The greater the manganese additions to the cupola the greater were the losses, running as high as 45 per cent loss for a calculated analysis of 1.15 per cent manganese. Therefore, no attempt was made to compensate for this loss as too much manganese would be lost by oxidation. Attempts to compensate for this loss were more successful in the ladle if too much of the alloy was not added.

22. No extra coke splits were used between charges of different cast irons. The same amount of coke, approximately 130 lb., was used between all charges. Lump ferro-manganese was not tried in the cupola.

23. The low test charges (Table 2) were composed of machine scrap, pig iron and returns and the calculated analysis was 2.10 per cent Si., 0.75 per cent Mn., and 0.10 per cent P. The charges for the chilled car wheels mix (Table 3) were composed of car wheels, low silicon pig and 10 per cent of steel. The calculated analysis was 1.05 per cent Si., 0.80 per cent Mn., and 0.11 per cent P.

Acknowledgment

The author is indebted to W. B. Craver, plant superintendent, Kanawha Mfg. Co., Charleston, W. Va., for his kind advice and assistance in this work.

DISCUSSION

In absence of the author, this paper was presented by M. F. Surls, Michigan State College, East Lansing, Mich.

MEMBER: Regarding that loss due entirely to oxidation, has the author made any analysis of the slag in their coke drop or is the loss due entirely to oxidation?

MR. SURLS: The author does not attempt to state the mechanism of how the loss occurs, he says simply the loss does occur. He points out, though, that the higher the temperature the greater the loss.

MEMBER: If he attributes it to the high temperature, it is oxidation.

MR. SURLS: That would be my interpretation.

J. A. BOWERS[1] (*Written Discussion*): After reading Mr. Davis' paper, we conducted a few tests on two of our cupolas. One of these cupolas is link shape, 72 x 102 in. inside the lining. In this cupola, the charges consist of 70 per cent pig iron, 18 per cent steel, 12 per cent cast iron scrap and 0.7 per cent Spiegeleisen made up into a 10,000 lb. charge. The molten iron is collected in a nine ton forehearth for distribution in the shop.

In the other cupola, which is 54-in. in diameter, the charge consists of 60 per cent pig iron, 35 per cent cast iron scrap and 5 per cent steel made up into 3000 lb. charges. The iron is tapped from the cupola intermittently.

A high manganese mix was melted in the 54-in. cupola. This was a

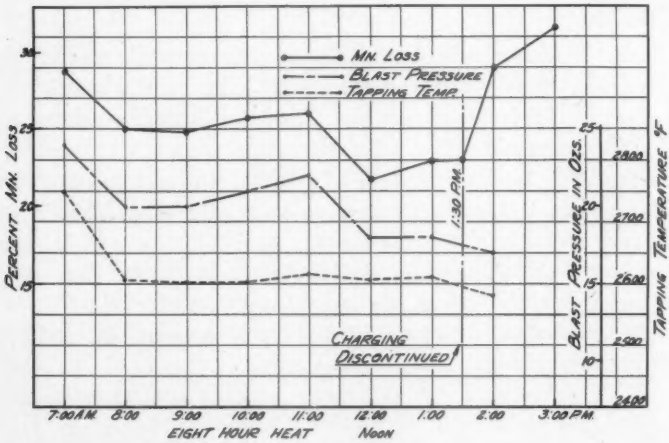

FIG. 2—MANGANESE LOSS IN THE CUPOLA—AVERAGE OF FOUR HEATS—CUPOLA 72-IN. x 102-IN., LINK SHAPE—MANGANESE LOSS BASED ON CALCULATED MN.—0.73 PER CENT.

[1] Melting Supt., American Cast Iron Pipe Co., Birmingham, Ala.

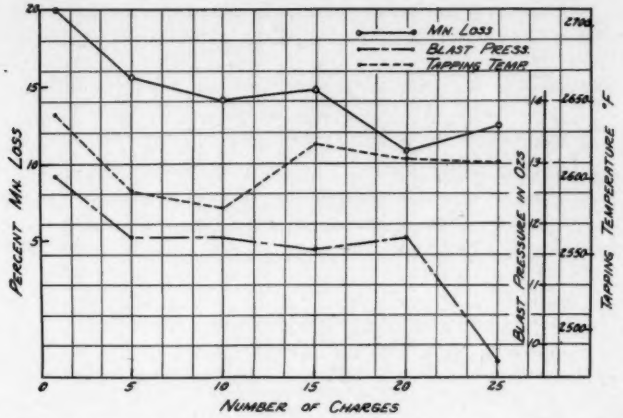

FIG. 3—MANGANESE LOSS IN THE CUPOLA (54-IN. DIAMETER) — AVERAGE OF FOUR HEATS — MANGANESE LOSS BASED ON CALCULATED MN.—0.61 PER CENT.

Ni-Resist mix and was made up into 2000 lb. charges. The manganese analyses for the large cupola were determined from samples caught each hour during the entire heat. The samples from the 54-in. cupola were caught from every fifth charge going into the cupola.

The points forming the curves in Figs. 2 and 3 presented herewith, are the average of four days melt. The curve for the high manganese melt is for one heat only and was of very short duration.

An examination of Fig. 2 discloses that the manganese loss follows not only the tapping temperature curve but also the blast pressure curve very closely. In these big cupolas charging is discontinued at 1:30 P. M. and the manganese loss increases rapidly from this time until the end of the heat; we think this is due to the increased velocity of the wind traveling through the charge. Although we cut the wind pressure to a certain extent, the melting speed must be maintained as nearly as possible to the end of the heat. Further evidence to sustain this contention is that we have found an increase in silicon loss near the end of each heat.

Figure 3 gives the data for a similar study for 54 in. diameter cupola. Again the manganese losses tend to follow the temperature curve but they also follow the blast pressure, although the blast variation is not as great as in the larger cupola. Charging is discontinued after the twentieth charge in this cupola and again we have a decided increase in manganese loss.

Figure 4 gives the data of a study of the high manganese melt. The heat was of such short duration that the graph does not mean much except to help sustain the contention that the blast pressure is the governing factor, for although the calculated manganese content of the charge is much higher than those in the large cupolas, the average loss is not as great.

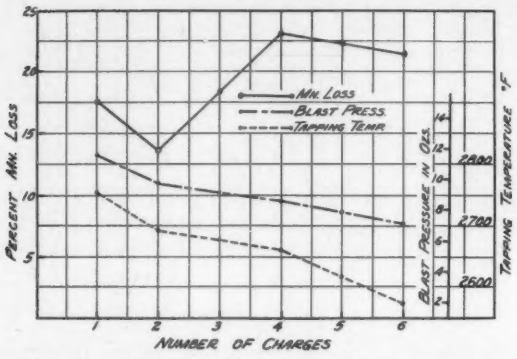

FIG. 4—MANGANESE LOSS DURING NI-RESIST HEAT IN 54-IN. DIAMETER CUPOLA, BASED ON CALCULATED MN.—1.54 PER CENT.

After studying these charts, we think that the blast pressure has more influence on the manganese loss than the tapping temperature. Although the individual curves do indicate that the manganese loss follows the temperature to a certain extent, the fact that we lose 25 per cent manganese on the average in large cupolas against 15 per cent in the 54 in. is very significant. The tapping temperatures, 2600 deg. F. average from both cupolas is the same. The only explanation we can think of for this is the higher blast pressure, 20 oz., for the large cupolas against 10 oz. for the small ones.

E. K. SMITH[2] (*Submitted in Written Form*): Mr. Davis' paper contains a good deal of interesting information, but some of the conclusions might be questioned until they are fortified with some information.

In the first place, manganese losses from 25 to 40 per cent in the cupola are abnormal and one is lead to suspect unduly oxidizing conditions, such as the lowering in the height of the bed. It must be remembered that manganese is a strong deoxidizer, and that wherever conditions are such as cause excessive oxidation, manganese losses are heavy.

Supplementary information would be very useful—What happened to silicon and carbon as manganese losses increased? Were these elements constant, or did they drop with manganese? It is frequently found that losses of silicon, carbon and manganese increase, especially with high percentages of steel, as the heat progresses, unless oxidation is regulated by the amount of coke used and the blast. It is, of course, well known that when the bed becomes progressively lower, losses of these elements are greater. (In this paper, the mixture giving the highest manganese loss contained 70 per cent of steel.)

It would also be interesting to note the analysis of sulphur as the heat progressed. Manganese acts as a desulphurizer under certain conditions, and sulphur analysis on the two mixtures as the heat progressed would be valuable.

[2] Electro Metallurgical Co., Detroit, Mich.

Since reading Mr. Davis' paper, actual manganese losses were determined at several foundries, the following being the general average results:

Foundry No. 1 Manganese loss—12 to 27 per cent
Foundry No. 2 Manganese loss— to 10 per cent
Foundry No. 3 Manganese loss— 8 to 21 per cent

Referring to Mr. Davis' statement that possibly some other form of manganese would have shown lower loss, it might be stated that in several cases where the manganese was added in the form of briquets and in other forms in comparative tests, the manganese briquets showed slightly lower losses than did the other materials.

DR. J. T. MACKENZIE[3]: The question was asked about the loss through the slag. About 20 years ago, we ran a whole heat and checked it. We found that approximately half the manganese loss was not in the slag. Of course, it is well known in the electric furnace production of ferro-manganese the loss from volatilization is quite high, and it seems to me with these temperatures and the blast pressure to carry the distilled manganese out the stack that the two things probably work together. In vacuum fusion method for oxygen, for instance, one of the main troubles is that the manganese distills from the crucible and then absorbs some of the oxygen. I think it will be found that the two will happen together, the oxidation and volatilization.

W. H. SPENCER[4]: Operating a 42-in. cupola, with quite a high coke ratio and a fairly low blast pressure our manganese loss is approximately 12.5 per cent, which is lower than is shown in this paper. Our melting temperature is higher than these quoted so far today. We did not find the manganese loss varied with the melting temperature, or even with the blast pressure. It seemed that the manganese loss is related more to the nature of the atmosphere in the cupola, which is affected by the combination of blast pressure and coke ratio.

H. RAYNER[5]: I would like to ask Mr. Bowers if he agrees with Mr. Davis in that the length of the heat affects the loss of manganese? In other words, is the loss of manganese greater towards the end of the heat than it is at the beginning? That has not been my experience. Take a heat that lasts 26 to 28 hours, the loss of manganese is not any greater on the last hour than it is on the third or fourth.

MR. BOWERS: The manganese loss does not increase according to the length of the heat. The thing that seems to affect it the most is when we cut or quit charging the cupola. After we quit charging, the manganese loss does increase very rapidly. We have also found the silicon loss increases. We must add silicon to the last few ladles coming out of the cupola.

MR. RAYNER: Would not that be due to the increase of velocity?

MR. BOWERS: Yes, we think so.

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[3] Chief Chemist, American Cast Iron Pipe Co., Birmingham, Ala.
[4] Metallurgist, Sealed Power Corp., Muskegon, Mich.
[5] Foundry Metallurgist, The Chrysler Corp., Detroit, Mich.

MEMBER: We run a jobbing shop and when we run a high test iron, we generally run about 6 or 7 tons at the beginning of the heat, and all we have ever had was about an 8 per cent loss in our manganese. We run 70 per cent steel. But, of course, we follow it up with regular iron.

MR. RAYNER: I would say the loss would not be as great when the manganese content is in the pig iron where it is more properly stabilized in the start than when added in the form of loose alloy. When the blast strikes unprotected concentrated alloy during the melting process, you have a much greater loss.

M. T. DAVIS (*Submitted as Author's Closure*): The discussion of my paper has brought to light important facts which make a modification of the conclusions desirable.

I believe Mr. Smith's remarks are pertinent. Improper combustion, due to a gradual lowering of the coke bed, and resulting oxidation, seems a reasonable explanation of my high manganese losses. In all cases, both total carbon and silicon were appreciably lowered during the middle and latter part of the heat. The sulphur losses showed no regular variation. Neither the coke nor the air were regulated to take care of a lowered bed as the heat progressed. As the study dealt with only high test cast iron (steel, 70 per cent), it is easy to see why Mr. Smith's remarks apply to the cupola studied.

We know that either a low bed or a high blast pressure will alter the zone of combustion and create excessive oxidizing conditions. That would explain why the manganese losses in Mr. Bower's cupolas are dependent upon blast pressure. Too high blast pressure may be as bad as a low coke bed.

One of the conclusions of my paper is that the amount of manganese is a determinent of the percentage lost. Comparison between the high manganese mix and the low manganese mix in Mr. Bowers data for his 54-in. cupola shows that although both mixes were melted with the same pressure, the high manganese mix showed an average loss of 20 per cent against a loss of 15 per cent for the low manganese mix. The amount of manganese charged may not be the chief determinent of the losses but, with other conditions equal, the higher the manganese, the higher will be the percentage of loss. This is particularly true when the extra manganese is in a concentrated and more easily oxidized form.

It is regrettable that the lengths of the heats used in my experiments were so short, being only 2 to 3 hours in length. It appears from the discussion that this time is too short to show what the equilibrium conditions would be. However, for the first 2 or 3 hours the manganese losses do show a variation depending upon the position in the cupola. My results and conclusions are confined to the warming-up period, and to high steel mixes; in which case the discrepancies between Mr. Bower's and Mr. Raynor's experiences and mine are easily explained.

My conclusions must further be amended to state that one of the most important determinents of the loss of manganese is the coke-iron-

air relationship within the cupola. If this is poor, and an oxidizing condition exists, the manganese losses will be high.

Both Mr. Bower's data and my own seem to point to the reasonable conclusion that, if other conditions are equal, higher temperatures would produce a faster rate of oxidation, and therefore higher manganese losses. This effect, however, seems to be slight compared to other effects brought out in the discussion.

Report of Committee on Methods for the Analysis of Defects in Nonferrous Castings

Members Non-Ferrous Division, American Foundrymen's Association:

At the Toronto meeting, in August, 1935, your Committee on Methods for the Analysis of Defects in Nonferrous Castings made its first preliminary report,[1] consisting principally of a classified list of casting defects. Feeling certain that the list was imperfect and incomplete we hoped that its publication would result in helpful criticism and suggestion. This has been the case.

The next step has been to list under each of these classified defects its probable and possible causes. It should be borne in mind that the terms used in listing defects were intended to be descriptive of symptoms rather than causes. The same symptom, in appearance, may result from very different causes, a troublesome fact which has sometimes been responsible for much difference of expert opinion.

In venturing to analyze foundry defects the committee realizes that it is entering upon controversial ground. With this in mind the committee has discussed the subject quite thoroughly, thus making use of the diverse experiences of its own members in an endeavor to arrive at something which would represent as many varying shades of opinion as possible. It was interesting to note in this discussion that what seemed to be decided disagreements were often due to a difference in phraseology, a different use of terms, or to different angles of approach because of varying experiences. It is thought that one of the accomplishments of this committee may be to dispel among foundrymen in general similar differences of opinion which may be more apparent than real.

With the material now in hand it is our intention to draw up a report which will be complete in form, systematically tabulating casting defects, each connected with probable and possible causes of trouble and suggested remedies, so that by a process of elimination the real difficulty in any particular instance may be detected

[1] *"Recommended Procedure for Analysis of Defects in Brass and Bronze Sand Castings,"* pp. 247-250, Feb. 1936 TRANSACTIONS. Also TRANSACTIONS OF A.F.A., vol. 43 (1935) pp. 247-250.

NOTE: This report was presented at a meeting on Nonferrous Founding at the 1936 Convention of A.F.A. in Detroit, Mich.

with more or less certainty. We do not imagine that the experienced foundryman will find it necessary to consult this chart every time he gets into trouble but we think that it will be of assistance in those cases which do not yield readily to the usual remedies.

The report will be complete in form rather than in fact because its ultimate completion will require revisions and corrections to be supplied by foundrymen who read it and use it. In this way only can we hope to arrive at an adequate presentation of this exceedingly complicated subject.

Respectfully submitted,

H. M. ST. JOHN, *Chairman.*

Report of Malleable Division Committee on Specifications

Members of the American Foundrymen's Association:

At the Toronto convention of the A.F.A., it was the sense of the Malleable Division Advisory Committee that any material which is cast as white iron substantially free of primary graphite and subsequently graphitized by heat treatment in such a way as to leave significant amounts of combined carbon should be called pearlitic malleable iron.

It is recognized that the combined carbon is not always present as pearlite but the term pearlitic malleable was adopted as the best compromise betwen simplicity and accuracy.

It was furthermore the sense of the Advisory Committee that such material should be described by grade numbers constructed as are the grade numbers for malleable cast iron in the present A.S.T.M. Specification A 47-33.

These suggestions were transmitted by your representative on A.S.T.M. Committee A-7 to that committee at its session in Pittsburgh and favorably acted upon.

Committee A-7 has further taken steps to reorganize its business by the adoption of by-laws, your representative being chairman of a committee of three to formulate these laws in conformity with the general principles applicable to all committees of the A.S.T.M. It is to be assumed that such by-laws will be adopted by the committee next June. In conformity with general practice, these by-laws will presumably require that for an individual to retain his membership on Committee A-7, he must attend at least one meeting of the Committee within any period of two consecutive years. This matter should be noted by the producer members of Committee A-7 who are also members of the A.F.A. It is very likely that Committee A-7 will enforce this rule quite rigidly unless there is very valid reason why a member or his duly appointed representative was not present as required. The rule is of major importance in keeping a committee active and our efforts should be in the direction of its enforcement, not of its evasion.

NOTE: This report was presented at a session on Malleable Cast Iron at the 1936 Convention of A.F.A held in Detroit, Mich.

Further action to be anticipated of Committee A-7 is in the direction of formulating the suggestions of the A.F.A. which the committee has already adopted into Tentative Specifications.

It would appear likely for the present that no particular yield points and ultimate strengths will be designated but only the means for designating the properties desired by buyer and seller be formally set forth.

The sub-committee on Cupola Malleable for Pipe Fittings was unable to present a report; the matter was referred back to the sub-committee with the advice of Committee A-7 that a specification be written for cupola malleable cast iron using the properties of the Manufacturers Standard Society. From the discussion in Committee A-7, it appears that this course was the only one which would not meet with unalterable opposition in some quarters.

Respectfully submitted,

H. A. SCHWARTZ, *Chairman,*
Committee on Malleable Specifications and A.F.A. Representative on A.S.T.M. Committee A-7 on Malleable Cast Iron.

Report of Committee on Study of Methods of Producing Liquid Steel for Castings

The above mentioned committee is composed of F. A. Melmoth, Vice-President, Detroit Steel Casting Co., Detroit, Mich., Chairman; George Batty, Consultant on Steel Castings, Drexel Hill, Pa.; Maj. R. A. Bull, Consultant on Steel Castings, Chicago, Ill.; John Howe Hall, Technical Assistant to the President, Taylor-Wharton Iron & Steel Co., High Bridge, N. J.; and C. E. Sims, Research Metallurgist, Battelle Memorial Institute, Columbus, Ohio.

F. A. MELMOTH[1]: This Committee exists at the present moment merely as a fact-finding organization, whose attentions will be devoted to interesting developments, both of new methods of steel production for castings, as and when they arise, and of new features in established methods of steelmaking.

Should it eventuate at any time in the future that actual investigation of any process becomes necessary, and funds were available, the present Committee would be already formed and ready to take over its arrangement.

At present, it merely hopes to make available to members of the Association any new facts which may become available on melting practices, if of interest from the viewpoint of steel casting production.

During the past few months the literature of the industry has been singularly void of any references of this nature.

The only new process which has become of interest to the steel founding industry is that of the Rotary furnace, fired with powdered coal, of the Bracklesburg or Sesci type, and, as I had an opportunity while in Europe last summer of seeing furnaces of the latter type in actual work on the production of steel for castings, it is thought advisable to pass on some of the points noted.

The Sesci furnace is similar in type and method of operation to the Bracklesburg, with the exception possibly of the type of burner which is used to burn the powdered coal. In the Bracklesburg it is normal to use a fairly high pressure, whereas in the Sesci furnace the lowest possible pressure which will convey the powdered fuel through the burner is that utilized. They are both of cylindrical shape, and are capable of either complete revolution or a rocking motion. The fuel, which is powdered anthracite coal, is fed to the furnace in controlled quantities, and is mixed and burned with air which is preheated in a regenerative system from the waste heat of the furnace itself.

The fuel burns with a very intense production of heat, so much so that the major problem, where steelmaking is concerned, has been that of the lining.

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[1] Vice-President, Detroit Steel Casting Co., Detroit, Mich.

NOTE: This report was presented at a session of the Steel Division at the 1936 Convention of A.F.A. in Detroit, Mich.

In the Crewe Works of the London, Midland and Scottish Railroad Company, in England, the Sesci modification of this furnace has established itself as the steelmaking unit in use, and the open hearth furnaces which were operating intermittently and uneconomically have been pulled down.

The steel I saw being made was of the normal analysis as used for railroad material, appeared to be very hot, and was in excellent condition for making rather thin castings. Control of analysis was not at that time absolutely perfect, but was improving daily.

I had an opportunity of seeing quite a large number of physical tests pulled which had been submitted to a straightforward annealing treatment, and without exception they were of a very high standard indeed, fully capable of meeting with an ample margin any specifications imposed upon steel castings of the carbon steel type.

As the furnaces had not operated for any appreciable length of time, it was not possible to obtain accurate figures of cost, but the promoters of this equipment claimed that the method of melting offered considerable advantages, from the economic viewpoint, over electric melting, and, in their opinion, the steel will be hot enough to cast into the thinnest of castings.

The pulling of the tests and microscopic examination of pulled samples was sufficient to convince me that from the technical viewpoint, however, the furnace was established as a steelmaking unit, and it remains to be seen whether continuous experience will so justify its promoter's opinion as to make it available for general steel foundry use.

In view of the shortness of this report, I have been asked to inaugurate a discussion around some of the steelmaking problems of the foundry, with a view, partly, to the arriving at ideas as to the points most commonly causing trouble, or upon which there exists the variation of opinion in the industry.

There are so many of these points that it was finally decided that six would be fairly representative, and I have formulated these as a series of questions. I trust that members will not hesitate to contribute to the discussion quite frankly their own experiences and opinions.

Question 1. To what extent, if any, does steelmaking furnace practice contribute the hot cracking of castings?

Question 2. Is it within the experience of members that porosity due to metal condition can occur even when analysis is orthodox in type?

Question 3. Does slag type and analysis, both in acid electric and open hearth melting, exert any considerable influence over the frequency and type of non-metallic inclusions?

Question 4. Does aluminum, used as a final deoxidizer, affect physical properties on account of the formation of alumina as a non-metallic inclusion, or because of its effect upon already existing inclusions by so altering their constitution as to affect the shape in which they occur?

Question 5. Are any facts available proving the superiority of either acid or basic practice in open hearth manufacture of steel for sand castings?

Question 6. Has any marked superiority of behavior in the molds of

molten metal of any particular alloy composition been noted, more particularly from the standpoint of resistance to hot cracking?

R. A. BULL[2]: I have been authorized by Dr. Clamer, a Past President of this Association and President of the Ajax Electrothermic Corporation and of the Ajax Electric Furnace Corporation, to state briefly that experiments have been under way for some time and are now being carried on with considerable encouragement to the experimenters, for the adaptation of a low frequency induction furnace for duplexing in the manufacture of steel.

This type of furnace is not now on the market. Obviously, it represents an interesting departure. That kind of job has not been done in America or in Europe up to this time commercially, although duplexing in the low frequency furnace in Germany has been done in connection with the manufacture of cast iron for treating portions of the mother metal.

Dr. Clamer expects, as the result of the development work that has been done, to be able, probably before the next Convention of this Association, to contribute such information on the subject that will further clarify the topic.

Speaking now along general lines, I would not be at all surprised to see duplexing, by some means, done very much more extensively in the steel casting industry in the future than it ever has been done. I have seen some extremely interesting illustrations of duplexing and triplexing for the production of some of these special metals that are on the borderline between steel and cast iron, with apparently very beneficial results metallurgically and economically.

MR. MELMOTH: I would like to turn now to the question: "To what extent, if any, does steel making furnace practice contribute to the hot cracking of castings?" My personal opinion is that steel making practice contributes very materially to the hot cracking of castings. I am not referring definitely to bad steel making practice as compared with good steel making practice as viewed from the normal standpoint, but that certain methods which have become acceptable are not the ones best calculated to prevent or give the maximum amount of resistance to hot cracking. Quite a number of open hearth slags, for instance, are tapped with unusually high iron oxide content, and it has been our experience by watching those heats very carefully, that where castings have a definite tendency to crack, that tendency is somewhat magnified when the final care in slags is not taken.

It has also been noted that, taken by and large, basic electric steel, when poured under reasonable conditions of temperature, has less tendency to crack than similar acid electric steel. Again, I am saying that is a matter of personal opinion.

J. M. SAMPSON[3]: For years we have operated both basic and acid electric furnaces, and sometimes on fairly complicated castings which we would like for a number of reasons to produce in acid electric, but we find that to do so we have to resort to too many brackets to hold the job. By

[2] Consultant on Steel Castings, Chicago, Ill.

[3] Foundry Engineer, General Electric Co., Schenectady, N. Y.

using the same molding practice and pouring the job from basic electric steel of practically the same composition, we find much less cracking. This, I believe, supports Mr. Melmoth's contention.

C. E. SIMS[4]: I cannot answer for basic electric steel. As far as my observations have gone, I have seen no outstanding difference in the cracking propensities of acid and basic open-hearth steel.

I was wondering as I listened to the foregoing remarks as to why basic electric steel should be superior in regard to cracking, and whether it is not in part at least due to composition. The outstanding difference would be in the sulphur content, and to a lesser extent, the phosphorus, but there would be other differences not shown by the ordinary analysis.

P. E. MCKINNEY[5]: My own opinions are pretty close to those of Mr. Melmoth as to the comparison between basic and acid electric. I think there may be even other factors than the composition as regards phosphorus and sulphur that play a part. As was brought out in the round table meeting, with acid steels, and particularly acid electric, there is quite a tendency for an over-reduced condition in the steel and of carrying our steel-making cycles so that we do not produce a normal steel. That is, we never carried through the cycle of oxidation where we get rid of gases and we keep building deoxidizers to keep the steel free from porosity, which produces the condition that, in any metal during the process of solidification, would induce cracks to develop even with the same sulphur and phosphorus content. Personally, I feel that the same castings and the same composition, taking average operating conditions, the basic electric is less susceptible to cracks than acid.

C. W. BRIGGS[6]: I have no definite data to present on fluidity at this time. We have made some studies on fluidity but merely in a preliminary way. In this work, we have employed the Bureau of Standards mold. It is doubtful that even if we did know everything about the fluidity of steel, we would find any correlation between fluidity and hot tear formation. I fail to see how fluidity can effect cracking conditions. The steel is solid when cracking begins. Even though it has very little strength at these high temperatures, it is still in the solid state. Of course, there may be a small amount of liquid material around the dendrites, but differences in fluidity would have no effect on crack formation. As you know, castings solidify from the surface inward and the envelope may crack and the fluid steel flow through to the outer surface, and in this way fill up and close the crack. The only place I can see therein the fluidity of the steel may be influencial in the study of hot tears would be that the more fluid the steel, the greater would be the tendency of the steel filling up the cracks that had developed early in the first formed steel envelope.

MR. MELMOTH: In regard to question 3, "Does slag type and analysis, both in acid electric and open hearth melting exert any considerable influence over the frequency and type of nonmetallic inclusions?"

This nonmetallic inclusions question may appear to some of our mem-

[4] Battelle Memorial Institue, Columbus, O.
[5] Metallurgist, Bethlehem Steel Co., Bethlehem, Pa.
[6] Naval Research Laboratory, Anacostia, D. C.

bers to have been a little over-worked. But test specifications are rising. And I assure you, nonmetallic inclusions in some of those specifications, such as 50 per cent reduction of area, with 90,000 lb. per sq. in. tensile and 60,000 lb. per sq. in. yield, are going to mean the difference between shipping the castings and finding them on the scrap heap.

MR. SIMS: Speaking in general terms, the question may be answered, "Yes." The type of nonmetallic inclusion, as Mr. Melmoth intimates, is closely associated with the problem of getting high physical properties in the steel. And nonmetallic inclusions are controlled incidentally through the slag. In our operations we have not paid a great deal of attention to the exact composition of the slags. In fact, to be frank, we have departed quite a distance from the admonition that good steel-making is essentially good slag-making. We have given minimum, rather than maximum, consideration to the slag. We have controlled our slag-composition to the extent of insuring proper oxidation during the working of the heat, and have otherwise let the slag more or less shape itself, especially in the acid furnaces. High fluidity has been considered a desirable characteristic of a slag, but I, personally, do not regard it as of importance to obtain any specific composition or color, providing the steel gets the proper working before deoxidation is undertaken. We have worked on the steel bath itself, endeavoring to obtain a low residual silicon content and a high temperature before deoxidation is started. We believe it important to reach the maximum temperature before deoxidation rather than afterwards.

Under these conditions, we have little trouble with the nonmetallic inclusions and get the type best suited for high ductility. There is no trouble at all in producing a low alloy steel to meet a specification of 60,000 lb. per sq. in. yield, 90,000 lb. per sq. in. tensile, 25 per cent elongation and 50 per cent reduction of area. It is a routine product of the shop.

The condition mentioned by Mr. McKinney and which is especially prevalent in the acid electric furnace, that of getting over-reduced steel, will contribute to the wrong type of inclusions. We have an unfortunate condition of nomenclature here. I believe we would have a better picture of the cause and cure for this condition if we would abandon the use of the term "over-reduced" and call it "under-oxidized steel."

Practical Sand Control in Gray Iron Foundries

By H. A. Deane,* Moline, Ill.

Abstract

To obtain sound castings free from surface defects, sand control is a necessity and, for rountine sand testing, a foundry worker with average intelligence can be trained to do this work. However, someone with the necessary experience is needed to correlate test results with condition of castings made. Laboratory tests are of value in selecting new sands and daily control tests should include those for moisture, permeability, and strength, with records kept and studied. Varieties of molding sands used should be kept to a minimum. Data on properties of sands for various classes of castings are listed by the author, who describes methods of making additions, both of natural and synthetic materials. Proper temper is stressed and facing control is described. The author points to sand control as paying for itself in a comparatively short time when properly conducted.

1. There are two principal and interrelated factors in the production of castings that are sound and free from surface defects. The more important factor is molding practice which may not be any more reliable than the human element; the other is sand control.

2. There is no mystery or complicated process involved in sand control. It is merely an easier and more exact way to obtain the proper sand and be certain that the sand is prepared and maintained in uniform condition when supplied to the molders. By using figures instead of guesswork, permanent and accurate records can be obtained. Sand control in the core room is also valuable but will not be discussed here because the purpose of this paper is to give some of the practical aspects of the benefits of controlling the variable properties of molding sand.

* Deere & Company.

Note: This paper was presented at a session on Sand Research at the 1936 Convention of A.F.A. in Detroit, Mich.

PERSONNEL AND SCOPE OF DUTIES

3. Anyone of average intelligence can be readily trained to do the routine sand testing. The use of apprentices for this work seems to work out advantageously both for the foundry and for training the younger men. However, after the tests have been made and recorded, this information must be applied. Someone, preferably with molding experience, should correlate the sand test results with the condition of the castings made in it. This man may be either the foundry metallurgist or the molding foreman.

4. It is very important and beneficial to have a daily meeting of the molding foreman, cleaning room foreman or inspector and the man responsible for the sand control. This meeting may be either formal or informal but some means of exchanging information as to the condition of the castings and methods of overcoming difficulties must be provided. Not only will plans be evolved for overcoming sand defects but also methods for eliminating scrap castings.

5. The sand control laboratory will be of value in selecting new sands. Here again we find that the best test of a new sand is practical use in the foundry. Experience is the best teacher but it may also be the most costly. Therefore any help that the sand laboratory can give should be welcome.

6. Tests should be made for fineness and clay content. This will be a guide in determining the type of sand. If the new sand seems suitable, a practical test should be made in the foundry by using this sand in comparison with the sand in use. The sand laboratory can follow these tests and collect the data. At present there are no standard laboratory methods for obtaining the durability of the sand but it is probable that an accelerated test will be evolved in the near future.

7. Shipments of new sand should be checked for fineness and clay content by the sand laboratory to make certain that a uniform material is being supplied. It has been found that such a procedure has a salutary effect on the supplier.

8. The sand laboratory should make the tests for moisture, permeability and strength of the different sands in use and keep daily records. The number of tests made on each sand heap or unit depends on the size of the heap or the number of times it is used per day. A convenient mimeographed sheet, such as the one shown in Fig. 1, can be used for recording the daily tests and the additions made.

BLANK CO.
Sand Testing Laboratory

Date	3/2/36				3/3				3/4				3/5				3/6			
Floor No.	M.	P.	S.	Additions	M.	P.	S.	Additions	M.	P.	S.	Additions	M.	P.	S.	Additions	M.	P.	S.	Additions
35	6.5	25	6.6	none	6.7	30	6.7	40# B.Q.	6.3	25	6.8	none	6.5	25	6.7	none	6.5	25	6.3	40# B.Q.
36	6.9	35	6.9	20# R.L.	7.0	30	6.4	20# R.L.	7.0	30	6.7	none	6.8	36	6.9	none	6.9	35	6.9	20# R.L.

FIG. 1—FORM USED TO RECORD DAILY TEST RESULTS AND ADDITIONS MADE.

9. Records should also be kept of the various batches of facing that are made up. All records should be available to the molding foreman so that the closest cooperation possible will exist between the sand laboratory and the molding department.

10. By means of these records and their correlation with the condition of the castings, definite standards of moisture, permeability and strength can be set up and maintained. The molding foremen will find these figures to be increasingly valuable in correctly placing the blame for defective castings and in suggesting means of overcoming molding difficulties. The actual reduction in defects and undesirable surfaces on castings will be surprising.

MOLDING SANDS

11. The number of molding sands required in a production foundry depends on the variety of castings produced. The molding practice and equipment will also influence this. No more than three grades of sand should be required in a foundry and often this number can be decreased if the molding practice is adjusted to it. The following grades of sand and their characteristics are used successfully in the larger foundries of the firm with which the author is connected.

Slinger Sand

12. For castings weighing up to 1,000 lb., and made on sand slingers, synthetic sand composed of Ottawa silica sand and a clay or bentonite bond is generally used because it is easier to prepare a synthetic sand than it is to secure an acceptable natural sand. This heap sand is maintained within the following standards which have been set up because past experience has demonstrated that these are best suited to the production of good castings:

Moisture Per Cent	Permeability A. F. A. Number	Compression Strength Pounds
4.5 to 5.5	80 to 100	7.5 to 8.5

13. For castings weighing from 100 to 300 lb. and made on heavy jolt strip machines or on the floor, either a synthetic bonded silica sand or an open natural sand is used. Due to the variations in castings made, the spread in specifications is rather wide, with the smaller castings being made in the finer sand. The following ranges seem to be suitable for the above castings:

Moisture Per Cent	Permeability A. F. A. Number	Compression Strength Pounds
5.5 to 6.5	45 to 70	6.8 to 8.8

Sand for Castings 1 to 100 Pounds

14. Castings ranging in weight from 1 to 100 lb. are usually made on the bench or with squeezers and natural sand is used. Sometimes, when an excessive amount of core sand finds its way into a heap, a clay bond is mulled in to maintain the strength. However, it is not advisable to use a completely synthetic bonded sand for this class of work because there is too much flowability for the usual molding practice. Here again, there is a wide range in the sand test standards to cover different castings because of the wide variations in jobs. Ranges which are suitable for this type of castings are as follows:

Moisture Per Cent	Permeability A. F. A. Number	Compression Strength Pounds
6 to 7	18 to 40	6.0 to 7.5

15. Sometimes for very small castings or where a particularly smooth surface is required, the permeability may be reduced below that shown above by using sand with a finer grain size. Another method is to mull in a small addition of sea coal at periodic intervals.

16. The present tendency is towards using sand with lower moisture and harder ramming which gives smoother and more nearly true castings.

SAND ADDITIONS AND PREPARATIONS

17. Natural sand additions are usually made by adding the raw sand to the heaps whenever the strength demands. It is far better to make frequent small additions than to allow the bond in the heaps to become too low and then add a large quantity of new sand. Daily sand tests will show when there is need for more sand to be added and this should be controlled by the sand laboratory.

Adding Bond and New Sand

18. When the clay bond in the heap sand is maintained consistently at 8 to 12 per cent the best molding results are obtained. This will vary somewhat depending on the bonding value and durability of the clay but the amount of clay bond should be kept as low as possible as an excess in the heap will reduce the permeability and cause defective castings.

19. The most efficient method of adding new sand is to mull it with about an equal volume of heap sand before spreading on heaps. However, if this is not possible, the alternative is to cut the new sand into the heap before the water for tempering is added. This procedure will distribute the new bond more thoroughly through the used sand and prevent the formation of clay balls.

Aeration

20. The use of an aerator will be found to be valuable as an aid to the sand cutter in preparing the sand heaps. The aerator acts as a mechanical riddle in fluffing up the sand and in removing core butts, tramp iron, etc. It also aids in producing a uniform sand condition by its mixing action. There is a need in the foundry for an aerator that will convey the sand to it when it is used on the sand heaps.

Synthetic Sand Additions

21. To obtain the most economical and efficient strength and permeability in synthetic sand additions, the mixture must be mulled with a small amount (1.0-2.0 per cent) of water before adding to the heaps. Usually these additions are made of 2 parts of silica sand, 1 part of clay bond and about 1 part of sea coal. These additions should be spread evenly on the heaps daily and in proportion to the requirements as shown by the daily sand tests.

22. The physical properties of a synthetic sand fluctuate more rapidly than natural sand. Therefore it is more important to make frequent tests on the synthetic sands. It is comparatively easy to vary the strength in this type of sand and to lower the permeability, but increasing the permeability of the sand is much more difficult proposition. Also, the moisture content in synthetic sand is much less stable than in natural sands. Therefore the price of good synthetic sand is continuous vigilance.

23. Occasionally a much used heap of synthetic sand will be satisfactory when tested by the sand laboratory but will feel

lifeless and there will be considerable difficulty in molding. This condition usually occurs in sand that has had large sea coal additions. It may be overcome by adding natural sand or by allowing the heap to be idle for a time.

Moisture Content or Temper

24. Possibly the most important single property of molding sand is the moisture content or temper, yet it has been the most neglected. The reason for this is that to obtain the correct temper considerable skill and experience is required. Furthermore, in the past, the molder's judgment was the basis of judging whether a sand was tempered correctly. An experienced molder would make allowances for variations in temper by controlling his ramming, venting, etc. In these days of high production molding and with fewer skilled molders available, some means of providing uniformly tempered sand must be provided. There are moisture testing devices available that will give accurate results quickly. Keeping the moisture of the sand at the lower limit of workability is very desirable because cleaner and fewer defective castings will be obtained.

25. Present day production molding demands uniform and correct sand temper, permeability and strength and the sand testing laboratory can be of inestimable value in obtaining these conditions. We believe that the molding sand testing should be done during or soon after the heaps have been cut over so that the sand preparation men may be guided by the test results.

FACINGS

26. In sand handling systems, the usual practice is to condition all the sand in such a manner that facing is unnecessary but in foundries where there is no central sand handling unit, the facing is usually mixed and mulled in special unit. It has been found that fluffing the mulled facing with an aerator is worth while. As this facing is to be next to the casting, it is important that the correct moisture, permeability, and strength be maintained in every batch. Therefore, frequent tests should be made to assure proper control and records kept so that reference can be made to them after the castings are poured.

27. Probably the most successful facing mixtures are composed with a base of heap sand plus sea coal and any additional bond and "opener" sand that may be required. The best results

will usually be obtained when the permeability of the facing mixture is lower and the strength is higher than the backing sand.

28. Each foundry has its own particular facing mixtures but perhaps some of those shown in Table 1 may aid in overcoming problems in other foundries.

Table 1

FACING MIXTURES

(Volume measurement)

Type of Facing	A	B	C	D	E
Heap Sand	30	46	42	43	40
Ottawa No. 1 silica	7	4		7	7
Natural sand			7		
Clay bond	9	½			
Sea coal	9	4½	6½	5	8
(Test Data)					
Moisture, percent	4.5–5.0	4.5–5.0	4.5–5.0	6.0–6.5	6.0–6.
Permaneability	45–60	45–60	45–60	25–30	10–18
Compression Strength, lb.	12–13	8.0–9.5	8.3–9.6	7.5–8.5	8.0–10

A—For 500–900 lb. castings made with sand slinger.
B—For 100–300 lb. castings made with sand slinger.
C—For 100–300 lb. castings made with jolt strip molding machine.
D—For general bench and squeezer work.
E—For small castings demanding very smooth surfaces.

29. The developing of suitable facing mixtures is the duty of the molding foreman but the sand laboratory should work very closely with them. After acceptable mixes have been established, it is up to the sand department to maintain them.

CONCLUSIONS

30. Sand control in the foundry will pay for itself many times over by supplying the molding department with correct and uniform sand. This means that one of the important variables in molding will be eliminated.

31. Sand control includes testing and recording the condition of the sand at adequate intervals in reproducible figures. It also helps the molding department to select the right sands.

32. Cooperation of the sand department and the molding department in interpreting results on the castings is vitally necessary. Only by working together can the maximum results be obtained.

33. Sand control will supply another valuable means of securing clean and sound castings, which is the main function of any foundry.

DISCUSSION

M. R. TAGGART[1]: I gather from this paper that the author is using a synthetic sand because no satisfactory natural sand has been obtainable.

MR. DEANE: That is right.

J. A. WOODY[2]: The author made the statement that the quality hardest to control was moisture. In one of our shops we mix 60 tons of synthetic sand an hour. We are able to control moisture within 0.1 per cent on a unit, not in a small batch. The sand is all handled by machinery.

CHAIRMAN R. F. HARRINGTON[3]: I believe we would be interested in knowing how you do it, Mr. Woody. What means do you use to accomplish these results?

MR. WOODY: We mix this sand in a concrete mixer in about two-ton batches. The water and clay are measured and added in the mixer. This batch of sand is put into a 60-ton revolving bin, then cut from the bottom of this bin onto a belt to another revolving bin and then cut from the bottom of the latter bin onto belts going to the ramming stations. By the time the sand gets to the ramming stations the moisure is very constant. As this sand is put into the 60-ton bin in hills and valleys, you will get a portion of two or more batches on each revolution.

CHAIRMAN HARRINGTON: How was the sample taken for the determination of moisture? Is it a cross-section sample? If you took this heap and spread out the 60 tons, would you find it uniform from corner to corner or center to end?

MR. WOODY: We have a man standing by the belt who takes samples as fast as he can run the moisture, perhaps 30 an hour, two or three times a day we get an absolutely true test from the laboratory. We are using the ram moisture test with the indicator hand on top of the test rammer head. By frequently calibrating the instrument against the true moisture content of the sand, this test checks the laboratory test fairly well.

DR. J. T. MACKENZIE[4]: I believe Mr. Woody left out one main point that makes it possible for him to control his moisture so carefully. That is that the original sand is practically bone dry. He does not have to guess how much moisture he has in it to start with, as do the fellows struggling with sand heaps.

MEMBER: Mr. Deane, do you have any trouble with the fines in your heaps? How do you control the fines, what effect do they have on the sand and do you remove them from the heaps?

MR. DEANE: We are able to control the fines in the sand on the units. To control the fines in the sand heaps, we specify the grade of

[1] Taggart & Co., Philadelphia, Pa
[2] Asst. Foundry Met., American Cast Iron Pipe Co., Birmingham, Ala.
[3] Metallurgist, Hunt-Spiller Mfg. Co., Boston, Mass.
[4] Chief Chemist, American Cast Iron Pipe Co., Birmingham, Ala

new sand that we add so that we do not get too many fines. After the fines are in, it is a difficult job opening up the heap.

MEMBER: Do you take your heap as a whole and put it through some mechanical system of removing the fines by exhaust?

MR. DEANE: Yes.

MEMBER: On this question of moisture control, some have a lot of trouble and some do not have. I wish to ask Mr. Deane if he has had anything similar to the experience which I have had. In hauling the sand on a long belt or a conveyor table, 300 feet or more with a very thin layer in front of a pusher, some natural sand will dry out before it gets to the end and some will not. The sands have the same bond apparently but the bond is obtained with a different clay percentage. We have an idea that the weaker clay in there tends to hold the moisture better than a little very strong clay.

MR. DEANE: We have noticed the same sort of thing. The natural sands tend to hold the moisture much better than the synthetic sands and it does not seem to be altogether a matter of permeability. With the same permeability for the natural sand and synthetic sand, the synthetic sand will dry out much faster. We have trouble sometimes with molds that have to stand open before they are closed. With the synthetic sand the corners will drop off and the molds are hard to patch. Our thought on that is that it is possibly due to different types of clay that are used.

CHAIRMAN HARRINGTON: One time, in one of these meetings, someone ventured the opinion glycerine was used in connection with this property of the loss of moisture or the loss of bonding characteristics of synthetic sands. I would like to know if anyone is using any material of that nature or has had any experience that they would care to contribute to this question that has just been brought up, that is the difference between the synthetic sand and the natural bonded sands in respect to their ability to hold the moisture content uniformly?

MR. TAGGERT: There are certain natural bonded sands that are being worked on sand slingers where the best results obtained are with a moisture content of around 5 per cent. These sands also have a tendency, if they should dry out a little, which they do more slowly than synthetic sands, to retain a certain dry strength which increases as the moisture dries out rather than causing the mold to break down in corners and such places. In other words, if you had a mold and allowed it to stand and air dry, you would have a harder mold surface with this sand two hours after you had let it stand than you would at the time the mold was made.

The sand in question is one which was developed to withstand the higher pouring temperatures of present day foundry practice which have developed with the producing of high-test iron.

The natural binder in this sand is a silica clay, which retains its moisture content longer than most clays, so that the drying out is not nearly so noticeable as in a synthetic sand. This sand, with a clay con-

tent of from 16 to 18 per cent, an average grain size of 72, a green compression strength of approximately 9 lb., has a permeability of around 85, and develops a dry strength of 38 to 40 lb. Its greatest green strength and permeability is with a moisture content of around 5.5 to 6.0 per cent. This green sand develops a mold hardness of 85. This will increase to double that mold hardness if allowed to air dry overnight.

MEMBER: As a point of interest, I might say that I have a friend in the jewelry business and I have seen him molding some rings. I felt the sand and I thought it felt so nice. He told me he was using glycerine. That is what the jewelers use. I do not know whether it has ever been used in a foundry or not.

M. J. LEFLER[5]: Along the line of synthetic sands drying out, we have noticed that when we use fuel oil as a substitute for all or part of the sea coal, we have much less tendency for the sand and the mold corners to dry out. We have not done anything excepting to try it in a rather small way on our sand slinger. I did try it once previously on a continuous molding unit and we got into trouble at that time from what we thought was poison in molders' arms caused by something that must have been in the fuel oil. But that was some years past. We tried it again and so far we have not had that bad effect the second time. Oil is much easier to apply than coal. Coal is a mean thing to put in, and as far as we can figure it, the oil is a little cheaper than coal. We have not entirely done away with the use of coal. We are trying the oil little by little so we don't get clear off the track before we find we are in trouble.

MEMBER: Mr. Lefler, are you using light engine oil like that used in Diesel engines, or is that crude oil?

MR. LEFLER: It is oil, such as we use in the firing of the forge furnaces. In fact, we just take it from our forge shop and put it on with a spray can.

MEMBER: I have had some experience along those lines in synthetic sand. We have been using oil to prevent the drying of corners. At the present time, we have not used it long enough to determine what effect it is going to have on the sand.

MEMBER: I would like to ask Mr. Deane how close he attempts to control the permeability and strength values of the sands? For example, if you wish to have a sand with a permeability of 30, can you control that, within three points?

MR. DEANE: No; probably between 25 and 35. The compression strength is kept within a one pound range.

MEMBER: Mr. Lefler mentioned the use of fuel oil and said he found it possible to use a lower moisture content in the sand than would be normally used in sea coal.

MR. LEFLER: I have to beg off on being able to say we are running moisture tests except by having the operator testing the common way by feel. So I cannot answer that question. I can add this, though, that

[5] Oliver Farm Equipment Co., South Bend, Ind.

you will notice where molders work a lot with their hands in the sands, where they are patching or ramming or tucking, they do not have quite the trouble they do otherwise sometimes with their hands getting calloused and cracked. Their hands stay soft.

MEMBER: I believe I can help in answering this question of moisture when using oil. In our foundry, we have retained the same moisture by using the oil. The effect at the present time is that it has eliminated the dry corners.

MEMBER: I would like to ask Mr. Deane, if he would say how often bench and squeezer sand heaps should be tested in order to insure the amount of control necessary to have good castings where the heaps are just used once?

MR. DEANE: Sand heaps that are used only once a day can be controlled if sand tests are made once a day. On very large heaps it may be desirable to make tests on different sections of the heaps.

Report on
Steel Castings Specifications Activities of A.S.T.M.

This report is being presented on behalf of your representative on the A.S.T.M. Committee A-1 on Steel, E. W. Campion, Bonney-Floyd Co., Columbus, Ohio, who is unable to be present.

This year has been productive of some very important actions that have been taken and are expected to be taken in the American Society for Testing Materials in connection with steel casting specifications, including a revision of the present tentative specifications for carbon steel castings for miscellaneous industrial purposes, which have been voted on in Sub-Committee VIII and are now being voted on in Committee A-1, and are expected to receive the endorsement of the Convention of the American Society for Testing Materials in June 1936.

If this action goes through as planned, the present specifications for miscellaneous castings will drop their present number and be called A27-36T. That action will be taken in connection with the cancellation of the old specifications which now bear the designation A27-24. (Final numerals indicate year of adoption.)

These new specifications which are expected to be made tentative by convention action next month include a total of eight grades of steel according to specified physical properties, ranging from 60,000 to 80,000 lb. per sq. in. tensile strength. That might seem to be a large number of grades to cover merely a range of 20,000 lb. per sq. in. tensile strength but, of course, it is necessary to take into consideration the different properties for ductility and for yield points. It was found necessary, in order to get a desirable agreement among all the groups that are interested in this matter, to provide for some grades that are very close to each other.

For example, there is one grade called B-1, Full Annealed, which is required to have 66,000 lb. per sq. in. tensile strength, 33,000 lb. per sq. in. yield point, 22 per cent elongation and 33 per cent reduction of area. Grade B-2, Full Annealed, is required to have 70,000 lb. per sq. in. tensile strength, 35,000 lb. per sq. in. yield point, 20 per cent elongation and 30 per cent reduction of area. The most interesting feature of this revision really consists in the development of required tensile properties for material that must be full annealed, and cannot be merely normalized.

NOTE: Presented before session on Steel Castings, Detroit Convention, May 6, 1936.

As these specifications stand, they will include one unannealed grade which is required to have 60,000 lb. per sq. in. tensile strength, 30,000 lb. per sq. in. yield point, 22 per cent elongation, and 30 per cent reduction; a normalized grade of 60,000 lb. per sq. in. required tensile strength; a full annealed grade required to have 60,000 lb. per sq. in. tensile strength; a normalized grade required to have 70,000 lb. per sq. in. tensile strength; the two full annealed grades I mentioned a moment ago, one calling for 66,000, another 70,000 lb. per sq. in. tensile strength; a normalized grade required to have 80,000 lb. per sq. in. tensile strength; and a full annealed grade to have 80,000 lb. per sq. in. tensile.

This is really a departure in A.S.T.M. specifications for steel castings, and emphasizes the significance of the kind of heat treatment that may be applied to the castings.

Another important action is being voted on now in Committee A-1 after having successfully passed through the approval of Sub-Committee VIII, covering the advancement to standard of the alloy steel casting specifications for structural purposes, A148-33T. It has been indicated it will be satisfactory to have these specifications advanced to standard.

The specifications for railroad steel castings, which have been tentative for a short time and are in accordance with the specification of the American Association of Railroads, are also being voted on in Committee A-1 for advancement to standard.

In the alloy field, specifications A157, which are the so-called high temperature specifications and include eight grades, are also being voted on for advancement to standard. These include the well-known 18 and 8 variety. Vote is also being taken now in Committee A-10, which has jurisdiction over high alloy steel containing chromium or chromium and nickel, on the tentative adoption of specifications for 18 and 8 steel castings that are intended particularly for resisting corrosion. It does not appear likely there will be much, if any, significant difference between those particular specifications and the specifications for the 18 and 8 castings that are under the jurisdiction of Sub-Committee XXII of A-1. Sub-Committee XXII has jurisdiction over high temperature applications, while Committee A-10 has jurisdiction over material to resist corrosion.

Respectfully submitted,

R. A. BULL.*

* Consultant on Steel Castings, Chicago, Ill.

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